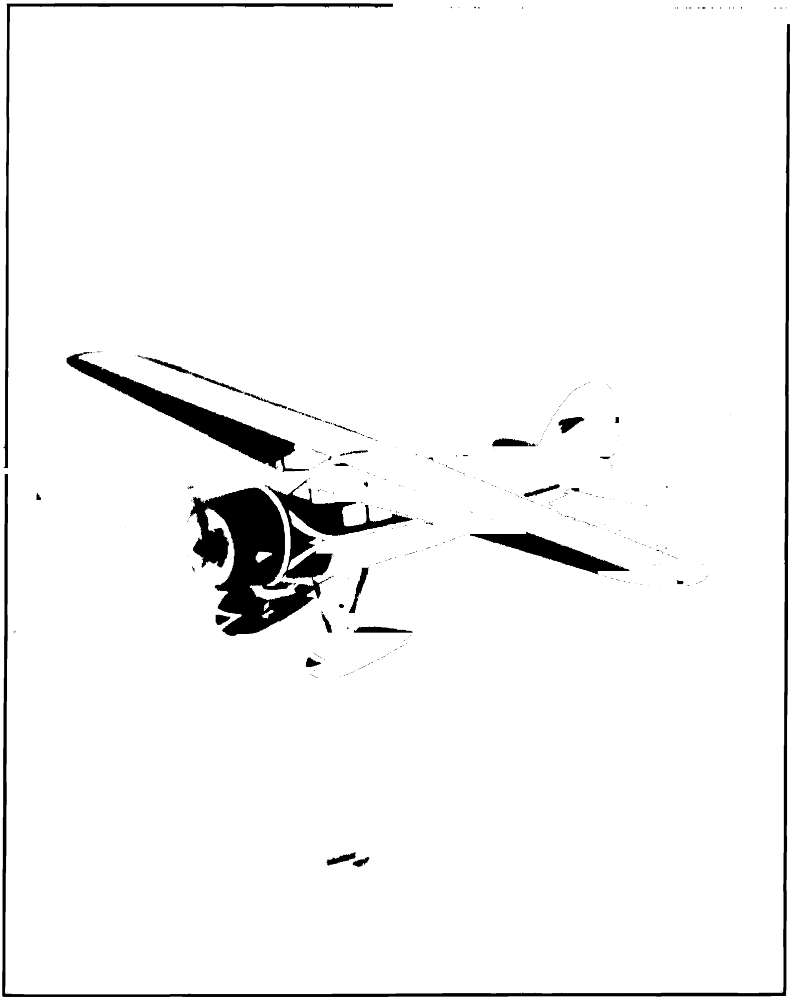
PRINCIPLES AND PROBLEMS OF AIRCRAFT ENGINES



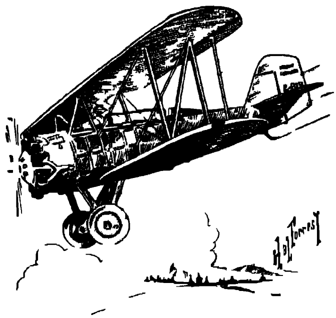
Frontispiece.

A Lockheed Vega Powered by a Pratt & Whitney "Wasp."

PRINCIPLES AND PROBLEMS OF AIRCRAFT ENGINES

BY

MINOR M. FARLEIGH



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To

MY MOTHER

PREFACE

The writer has attempted to present to the reader, in a non-technical form, a sufficient amount of material on the servicing of aircraft engines for him to pursue intelligently the important groundwork involved in the maintenance of engines.

The future of aviation depends to a large degree upon the caliber and knowledge of the ground personnel, for upon these men falls the responsibility of maintaining the dependability which engineering has built into modern aircraft engines. Not only from an economic point of view are these men essential, but the lives of pilots and passengers lie in the dependability of the power plants and the mechanics employed in the maintenance of equipment.

As in any line of endeavor, in order to become proficient in aeronautical work and to foresee what the practical side holds in store, we have to learn and master fundamental principles and couple them with the experience of the men who applied them. Certain principles being applicable to new situations and conditions, we are primarily interested in mastering those principles, so that we may detect any radical variations from them. At the present stage of aircraft engineering, as applied to the power plants, there is a dominating conventional design which underlies all successful developments. Today we expect the gasoline aircraft engine to be based upon the four-stroke cycle principle, with a carburetor which will handle liquid fuel, with an ignition system in which an electric spark is employed, and with a few accessories which have, up to the present, been found to be indispensable.

An effort has been made to make this book appeal to the licensed mechanic, the licensed pilot, the operator, and the student who desires to qualify as a dependable mechanic on aircraft engines or an efficient pilot, and if these pages contribute in any way to a better training in the aeronautical field, the writer will feel that his objective has been attained.

The writer wishes to express his appreciation to Mr. Robert Landgrave for numerous drawings appearing in this volume, and to acknowledge his indebtedness to the following manufacturers for their cooperation in furnishing data and illustrations pertaining to their products:

The Pratt & Whitney Aircraft Co.
Kinner Airplane & Motor Corporation.
Wright Aeronautical Corporation.
The Warner Aircraft Corporation.
Packard Motor Car Company.
Stromberg Motor Devices Company.
Scintilla Magneto Co., Inc.
General Electric Company.
Lockheed Aircraft Corporation.
The Hamilton Standard Propeller Corporation.
American Cirrus Engines, Inc.
Curtiss Aeroplane & Motor Co., Inc.
The B. G. Corporation.
A C Spark Plug Company.
Zenith-Detroit Corporation.
The LeBlond Aircraft Engine Corporation.
Society of Automotive Engineers.
Axelson Aircraft Engine Co.

MINOR M. FARLEIGH.

CONTENTS

ERRATA

Page **18**: Whirlwind J-5, should read: **J-6**

Page **41**, 3rd line should read: **Running** clearance (cold), 0.010 in. (J-5: 0.040 in.)

PRINCIPLES AND PROBLEMS OF AIRCRAFT ENGINES

CHAPTER I

ELEMENTARY THEORY AND DESIGN OF AIRCRAFT ENGINES

The development of the aircraft industry since the Wright Brothers established motored flight within the realm of the possible has been, to no small degree, due to the development of the internal-combustion engine. And the evolution of the internal-combustion engine as applied to aircraft has hinged upon research which made possible a reduction in weight per horsepower. From the time of the first Wright engine, which weighed about thirteen pounds per horsepower and which was an achievement for that period, there has been a constant refinement in design, construction, and material which has made possible dependable engines weighing as little as a pound and a half per horsepower.

Motored flight being limited to about twenty-five pounds per horsepower, gross weight, it is apparent that flight in heavier-than-air machines rested in building an engine which weighed less than twenty-five pounds per horsepower in order to have a margin in weight to be allotted to the airplane structure.

The progress in weight reduction per horsepower has been wholly confined to increasing the efficiency of the gas engine and to the selection of materials which would permit weight reduction without detracting from the strength of engine parts. Fundamentally the principle upon which all successful aircraft engines function has not changed since it was first worked out by Dr. Otto.

The Otto principle or cycle of operations in the gas engine, better known as the four-stroke cycle, requires four strokes of the piston for its completion. The *cycle* is the series of events which occur in regular order, repeated over and over again. During a stroke of the piston an event of the cycle takes place, and the piston must travel four strokes before the cycle is completed.

The first event of the cycle is *suction*, or *intake*, which, theoretically, starts at top center with the opening of the inlet valve as the piston

starts downward in its travel, and ends, theoretically, at bottom center with the closing of the inlet valve. (See Fig. 1.) The second event, *compression*, takes place during the up-stroke of the piston, while both valves are closed, thereby compressing the charge. When the piston reaches top center, ignition of the compressed gas takes place, and the third event, *power*, occurs during the down-stroke of the piston. The fourth event, *exhaust*, starts at bottom center with the opening of the exhaust valve and ends at top center with the closing of the exhaust valve, thereby completing the four events during four strokes, which is the finished cycle.

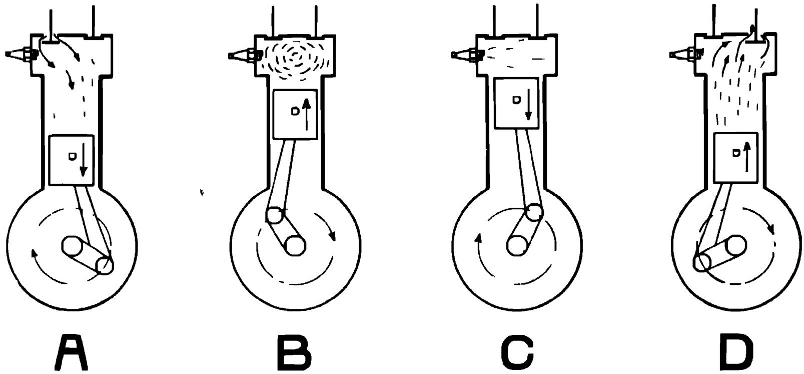


FIG. 1 —The Four-stroke Cycle.

(*A*) The suction stroke (*C*) The power stroke
(*B*) The compression stroke (*D*) The exhaust stroke

Starting with the simple Otto cycle applied to one-, two-, and four-cylinder engines, constant research has resulted in increased efficiency of Otto-cycle engines by developing the efficiency of each event of the cycle. Reduction of the space between the piston head and cylinder head, the increasing of the inlet-valve diameter and refinements throughout the induction system have increased the weight of the charge of combustible gas drawn into the cylinder during the first event of the cycle, or the suction or admission event. The reduction of the space between the piston head and the cylinder head likewise has increased the efficiency of the compression event indirectly through its influence upon the third event (power), inasmuch as the effective pressure during the power stroke is the result of the degree to which the gas is compressed during the compression stroke for a given bore and stroke. Refinements in exhaust-valve timing and increasing the area of the exhaust port have resulted in improving the fourth event,

and this improvement in scavenging of the cylinder has had a markedly beneficial effect upon the other events because of the value in preparing the cylinder for the succeeding events. Therefore, while the principle

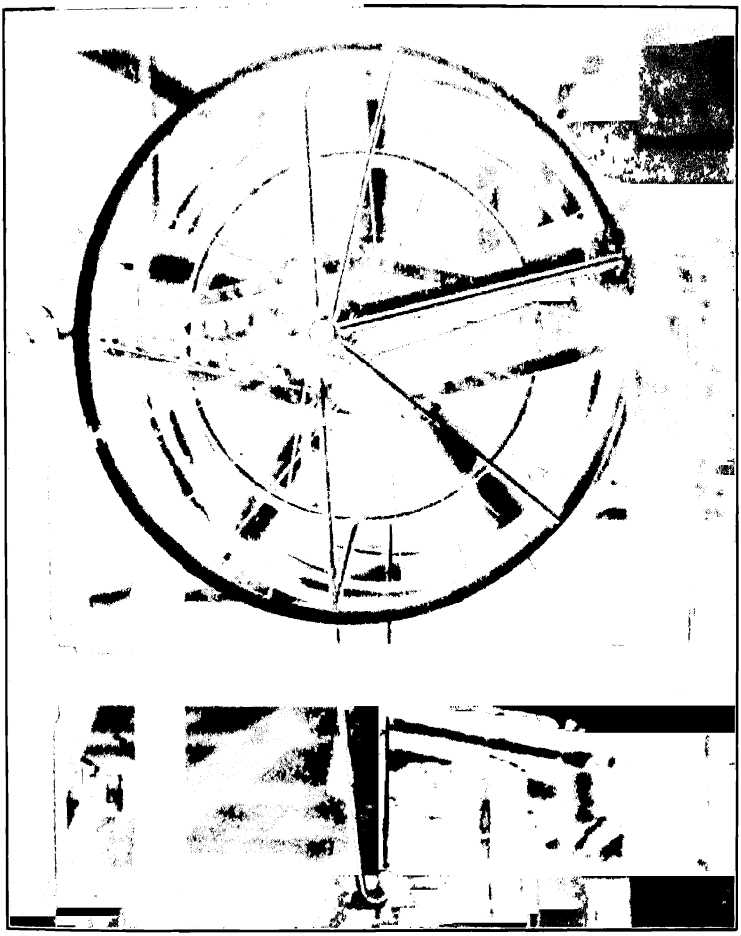


FIG 2 —The Manly Radial Water-cooled Engine

has remained the same, increased efficiency has been brought about by increasing the rate and weight of fuel injection, increasing the effective pressure applied to the piston, and increasing the rate of burnt-gas ejection.

The original conception of the reciprocating engine as the most feasible means of utilizing the Otto cycle has consistently been verified. Notwithstanding its disadvantages, the reciprocating engine, which is the engine principle in which the to-and-fro movement of a piston is converted into a rotary motion by means of a connecting rod and crank, has successfully held its own. To offset the disadvantages of the piston-and-crank principle, as well as the disadvantage of the four-stroke cycle which provides power to the piston less than a half revolution in every two revolutions, the cylinders of the engine have increased

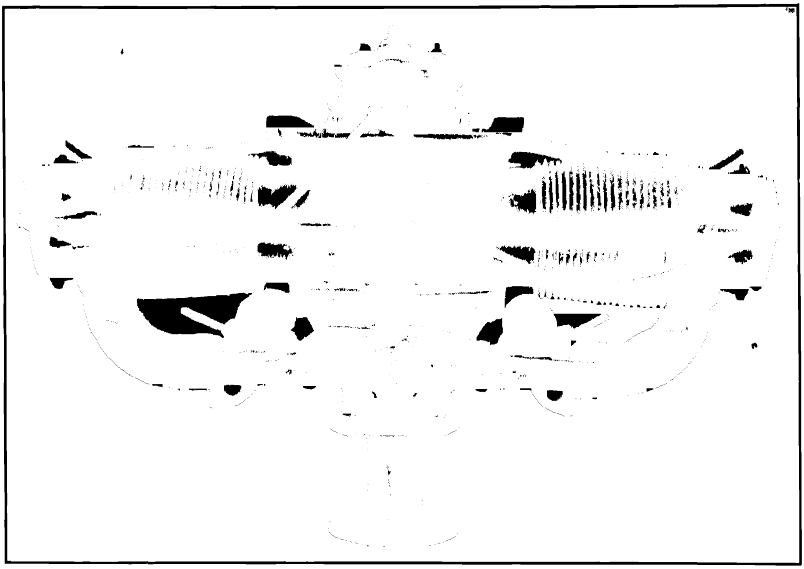


FIG. 3.—The Two-cylinder Lawrance Engine

in number in order to bring about smoothness in operation by an overlap in power events; and the weight of the reciprocating parts has been reduced to a minimum to offset, to some degree, the forces resulting from stopping and reversing the reciprocating parts at top and bottom centers.

The necessity of weight reduction in engines for aircraft has resulted in the nearest approach to perfection, for in order to increase the horse-power for a given weight, the losses encountered in the four-stroke cycle principle have had to be minimized to as great a degree as possible. The ideal engine, which has never been even closely approached, would deliver 100 per cent of power from the fuel consumed. From engines

which were but from 10 to 20 per cent efficient there have been achieved engines well above 30 per cent in efficiency.

The internal-combustion engine, being a heat engine, suffers a tremendous loss with the opening of the exhaust valve and the resulting escape of heat. Likewise, the limitation of operating temperature

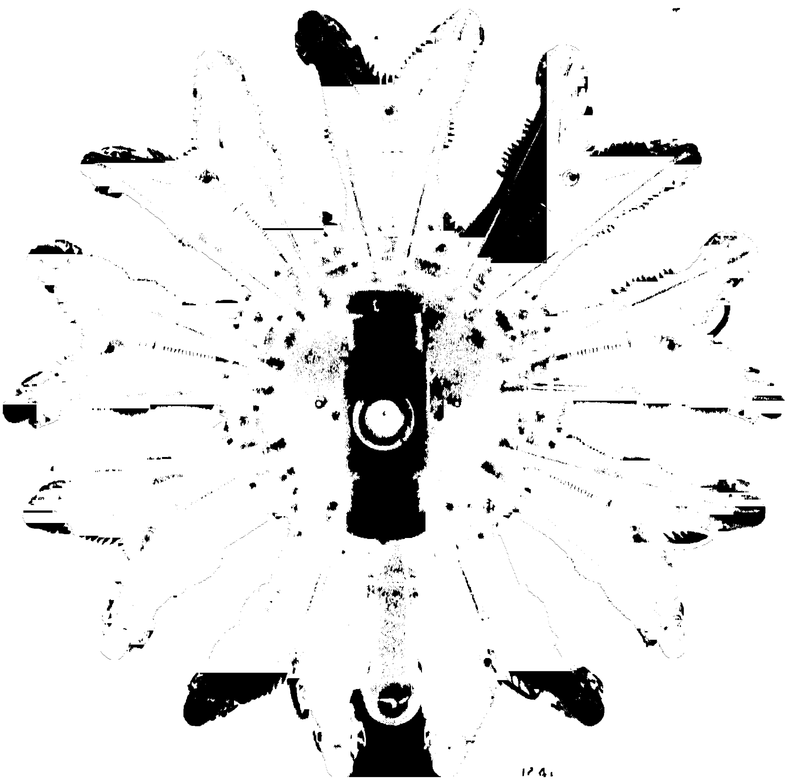


FIG. 4.—The Pratt & Whitney "Wasp."

for the engine, which must be kept down on account of friction and lubrication problems, as well as the expansion of materials, has a detrimental effect upon the thermal efficiency of the gas engine. These heat losses when combined with the losses through friction brought about by the engine driving itself leave less than 35 per cent for useful work at the propeller shaft of most engines, depending upon the designer's ability to minimize the losses.

Besides the problem of minimizing heat losses, the aircraft-engine designer had been confronted with the task of constructing an engine which would operate at full throttle over long periods, without a lowering of power or without structural failures, and which, at the same time, would be lighter in weight than any other type of automotive engine.

FIG. 5.—The Wright Whirlwind J-5.

It is to the credit of Charles M. Manly that as early as 1902 he constructed a five-cylinder water-cooled radial engine which weighed less than 3 pounds per horsepower; yet his foresight was not appreciated for many years. With the early Wright engines of the vertical type, and the Manly radial engine as pioneers in light-weight engine

building, there has followed every conceivable design. From the first Wright four-cylinder water-cooled engine there sprang two- and three-cylinder engines, both air-cooled and water-cooled; six-cylinder verticals, air-cooled and water-cooled; sixteen- and thirty-two-cylinder water-cooled; air-cooled rotary radials; and the very successful V-type engines of eight and twelve cylinders.

During the war and during the post-war period we found designs wholly different, yet giving a good account of themselves, establishing

Fig. 6.—The Curtiss Conqueror Engine.

the fact that material and workmanship were more important factors than design, providing the design was reasonably within conventional practice. Since the war many changes have taken place in engine design with the air-cooled radial engine dominating the new production field, and the air-cooled engine as supreme as the water-cooled engine was during the war and post-war periods.

Notwithstanding the multitude of successful air-cooled engines at present in production, the water-cooled engine is far from being in discard, for the Packard and Curtiss companies are building twelve-cylinder water-cooled engines quite similar to the twelve-cylinder

water-cooled Liberty Engine, which closely approach a pound and a quarter to the horsepower.

During the experimenting with various types and designs it has been learned that any fairly well-designed engine can be made to give satisfactory service if the proper materials are employed in its construction, and that proper material and workmanship which would prevent structural failures would not insure dependability if the acces-

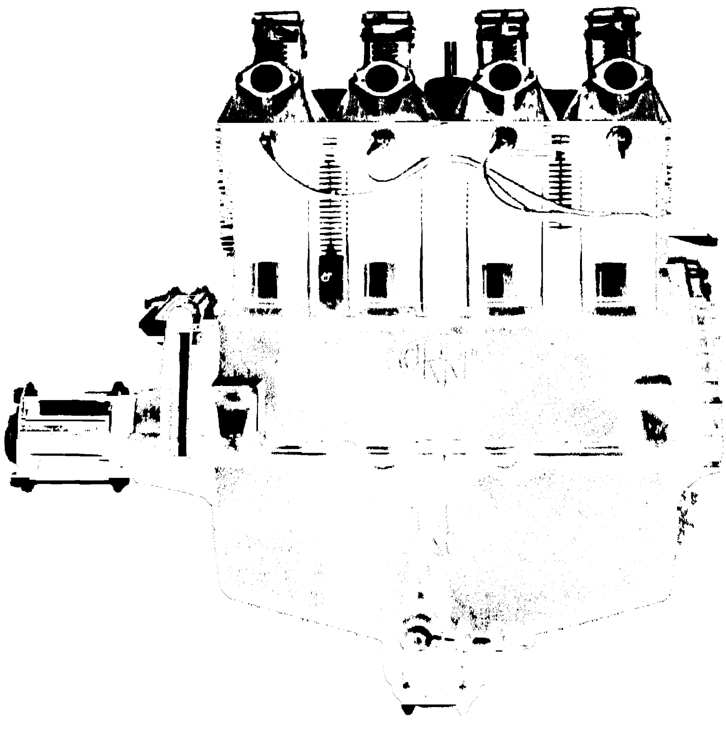


FIG. 7.—The Cirrus Engine.

sories, such as the carburetor and ignition system, were not the equal of the engine in reliability. Aside from these factors, an engine must be serviced periodically and intelligently in order to maintain the dependability built into the engine and its accessories.

Difference in opinion of designers is not wholly the reason for various types of aircraft engines. There are types which are peculiarly suited for particular work. A four-cylinder, air-cooled, in-line engine of

400 horsepower would be quite impractical; yet the four-cylinder, air-cooled, in-line Cirrus Engine of 100 horsepower has a record of performance which has not been surpassed for varied service in the air by any other type of engine. The four-cylinder, air-cooled, in-line engine, while not feasible in large power plants, is well suited to light planes where more than 125 horsepower is not required. The in-line engine provides almost perfect stream-lining, an advantage of paramount importance in aeronautics, which may eventually bring about a standardization on in-line engines, or to the undeveloped but similar opposed-in-line engines.

CHAPTER II

VALVE TIMING

Valve timing and the cycle principle are so closely associated that it must be clearly understood that each stroke, which is an event of the cycle, theoretically starts and ends at a dead center; therefore, each stroke is one-half of a revolution, or 180 degrees; two strokes, one revolution, or 360 degrees; and the complete cycle of four strokes, 720 degrees.

Valve timing is the opening and closing of the inlet and exhaust valves at the proper time. The duration of the inlet period and the exhaust period depends upon the contour of the cams actuating the valves. With correct clearance at the valve tappet adjustment, the duration of the intake or exhaust period cannot be changed, though the beginning and ending of the periods can be timed by meshing of the camshaft gear with the crankshaft gear. This operation is termed *timing the valves.*

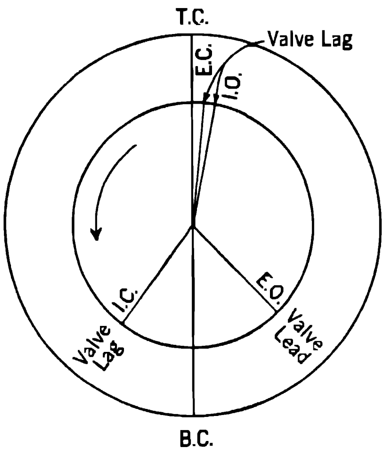


FIG. 8.—Valve Lag and Valve Lead.

NOTE: Anti-clockwise arrows indicate timing marks are on a timing disc attached to crankshaft.

VALVE LAG AND VALVE LEAD

With the inlet valves opening and closing on centers, where the layman would expect them to open and close, there would be little confusion in grasping the fundamentals of inlet-valve timing. Owing to the movement of gases and to the high speeds attained by the piston, it becomes necessary to give varied openings to the inlet valve. A late opening is frequently found in the opening of the inlet valve, the late opening being referred to as *lag,* meaning *tardy.* It must not be understood that the inlet valves of all engines open late, for in many cases a *lead* is pro-

vided to the opening of the inlet, as in the Wasp, Hornet, Whirlwind, Kinner, Scarab, and Cirrus. A lag is provided for the closing of the inlet valve in all cases. The exhaust valve is given a *lead* in its opening, that is, an early opening, or one before bottom center is reached, remaining open until top center, or after top center in most cases, thereby creating another valve lag. See Fig. 8.

LOW-SPEED ENGINE TIMING

In comparing engines there are great variations found in valve timing, depending upon many factors, such as volume of cylinder, compression, position and size of valves, lift of valves, stroke of piston, length of connecting rod, and, most important, the speed of the piston. The principle of valve timing remains the same, and yet the variations cause some confusion. In an engine designed to operate only at low speed, for instance, a marine engine or a stationary engine, the valves open and close practically upon centers. The inlet valve usually opens at top center and closes at bottom center, or slightly past, as this is a duration for the inlet period which is suitable for low piston speed. The exhaust valve is given a slight lead to its opening, permitting the pressure within the cylinder to be lowered before bottom center is reached. Back pressure upon the piston at bottom center, as well as back pressure during the exhaust stroke, is prevented by the slight lead to the opening of the exhaust valve. The long period of power applied to the head of the piston gives a maximum amount of thrust throughout the working stroke, and is suitable for low piston speed. See Fig. 9.

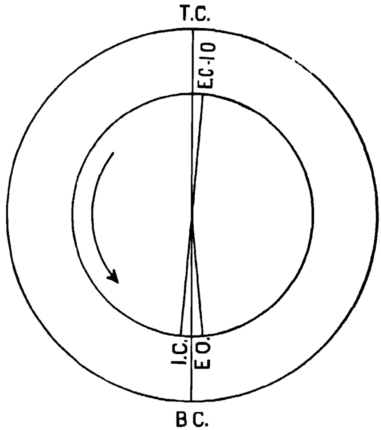


FIG. 9 — Low-Speed Valve Timing.

NOTE. Anti-clockwise arrows indicate timing marks are on a timing disc attached to crankshaft

HIGH-SPEED ENGINE TIMING

Engines designed for aircraft, which fall under the class of medium-speed engines, and engines designed for other duty, which turn at very high speeds, have valve timing radically different from the timing found in engines for low-speed duty. Aside from the many factors,

previously mentioned, which govern valve timing, the speed of the piston compels extreme lag to be given the opening and closing of the inlet valve in many cases, as well as an extreme lead and lag to the opening and closing of the exhaust valve. Irrespective of crankshaft speed, the speed of the piston has the most important bearing upon the duration of the inlet and the exhaust periods. See Fig. 10.

A lag of varying degree, explained under Valve Laps, is sometimes given to the opening of the inlet valve for high-speed engines, and an extremely late closing is given to the inlet valve, owing to the high speed of the piston, which causes the piston actually to "run away" from the inrushing gas. A vacuum still exists in the cylinder after the piston has passed bottom center, and, owing to the great piston speed, remains while the piston is ascending upon the compression stroke. This vacuum and the momentum of the inrushing gas create a condition within the cylinder which necessitates the inlet valve being held open until the ascending piston has reached a position where the pressure within the cylinder is as near atmospheric pressure as possible. The inlet valve is then closed to prevent the piston pushing the gas back through the inlet port, a condition which may arise at low speed in an engine having the inlet valve timed to close very late.

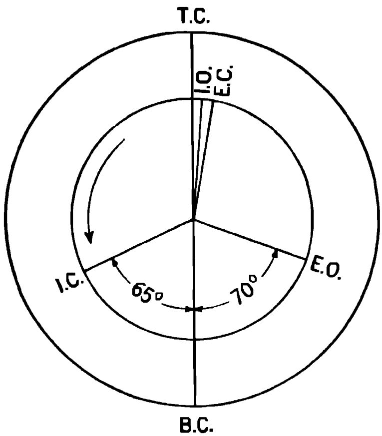


Fig. 10.—High-Speed Valve Timing.

Note: Anti-clockwise arrows indicate timing marks are on a timing disc attached to crankshaft.

The lead given to the opening of the exhaust valve is directly governed by the speed of the piston, for a piston traveling at a high speed will cover a given distance of the stroke faster; therefore, in order to lower the pressure within the cylinder before bottom center is reached, the pressure must be relieved while there are sufficient expanding qualities for ejection out through the exhaust port. See Fig. 11.

Owing to the many factors governing the lead to the opening of the exhaust valve, no setting in degrees can be given, as an example, except the average lead. The average opening of the exhaust valve will be between 45 and 50 degrees before bottom center, this average varying each year, owing to the changes in valve timing and the number of engine models upon the market. In some engines, the lead will

amount to but 30 degrees before bottom center, and in other cases, a lead of 75 degrees is given.

The use of higher-speed engines, during recent years, has increased the average opening of the exhaust valve, for the speed of the piston compels extreme lead. It should be clearly understood that, regardless of the speed of the engine, the exhaust valve opens in the power stroke; therefore, the *exhaust event* begins well into the power stroke, and by the time the true exhaust stroke starts at bottom center, the greater part of the heat and pressure has been expelled. The exhaust stroke which follows serves the purpose of scavenging the cylinder of stray burnt and unburnt gases.

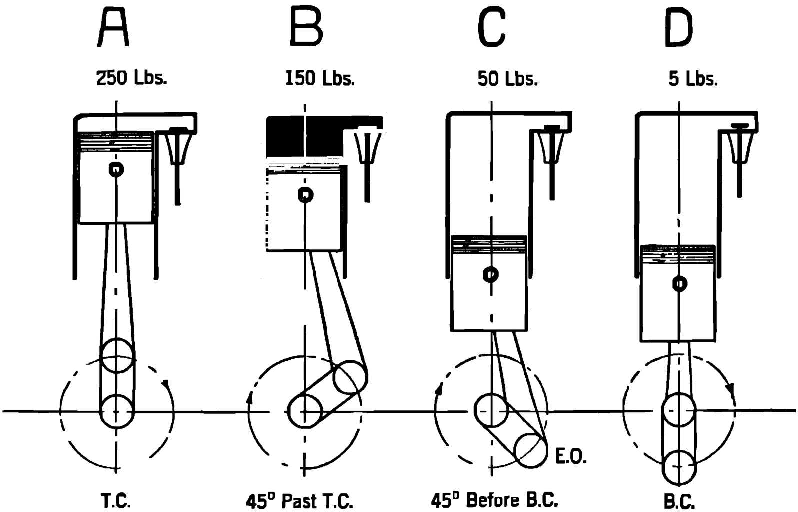


FIG. 11.—The Variation of Pressure During the Power Stroke.

Though exhaust is in reality accomplished in the power stroke, the exhaust stroke, so called, beginning at bottom center, would be forced upon engine builders, inasmuch as it would not be possible to close the exhaust valve before top center was again reached even if there were no stray gases to drive from the cylinder, for closing the exhaust would create compression during the exhaust stroke. In order to begin a new cycle, it is obvious that the piston must be at top center to start the suction stroke, and the up-stroke necessary to bring the piston at top center serves well as a scavenger.

The closing of the exhaust valve is more or less a matter of opinion among engine designers, for in this matter there is a wide variation found. This is undoubtedly a critical point, and owing to the variable

speed of an engine, there is an ever-changing condition becoming more manifest as the engine speed is increased. This condition which takes place at top center or after top center, where one cycle is completed and another begins, is taken up separately under Valve Laps.

AVERAGE-SPEED ENGINE TIMING

When it is realized that valve timing is governed chiefly by the speed of the piston, and the speed of the piston has a wide range, from throttled speed to its maximum speed, it follows that a valve timing which would give high efficiency at low speeds would not be efficient at high speeds, and *vice versa*. An engine intended to operate only at high speeds would have to be provided with a camshaft which would insure correct valve timing at high engine speeds, in order to be highly efficient at those speeds. An example of this is found in engines for speed contests, which are intended to perform efficiently only at high speeds, cruising speed efficiency being of no interest.

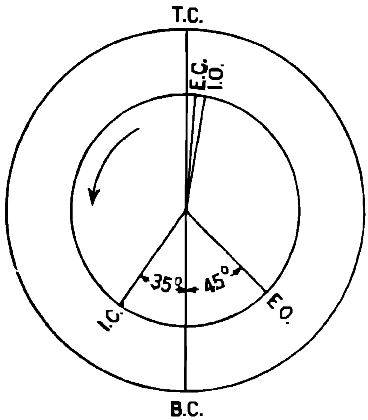


FIG. 12. Average Valve Timing

NOTE Anti-clockwise arrows indicate timing marks are on a timing disc attached to crankshaft.

While aircraft engines are classed as medium-speed engines, they are subjected to fairly high speed over long periods, and must be provided with a valve timing suitable for the entire range of engine speeds. While extremely high-speed engines are not required for aircraft, the high-speed valve timing encountered is employed because such engines operate at a constant speed which is a near approach to a high-speed engine range.

Aircraft engines turning in excess of 1800 revolutions a minute when throttled for cruising speeds must be provided with a valve timing suitable for a wide range of speeds. It is obvious that an average timing must therefore be given to the valves, to insure good performance throughout the speed range. Under conditions which would give maximum efficiency to a certain engine by having the exhaust valve open 60 degrees before bottom center for high speed, and but 30 degrees opening before bottom center to give maximum efficiency for low-speed work, the designer must strike an average between these extremes, which would be about 45 degrees. See Fig. 12.

VOLUMETRIC EFFICIENCY

The same condition arises with the opening and the closing of the inlet valve as occurs with the exhaust valve. Like the exhaust, the inlet must be timed to give the highest efficiency at cruising engine speed and high speed. The effect of the piston speed is as great upon the duration of the inlet period as it is upon the duration of the exhaust period. Upon the length of the inlet period, in relation to the speed of the piston, depends to what degree the cylinder receives a fresh charge of gas. The ideal strived for, and never attained under any normal condition, is 100 per cent volumetric efficiency, which means nothing more than charging the cylinder completely with a volume of gas of atmospheric pressure at an average temperature of 60° F

At very low piston speeds, high volumetric efficiency is obtained by having the inlet valve opening at top center and closing at bottom center, or slightly past bottom center. Opening and closing the inlet valve on centers is not, however, a sufficient duration for the inlet period when the piston speed is increased. Greater time must be allowed for atmospheric pressure to inject the gas into the cylinder, and when the piston speed is high, a lag of 70 or 80 degrees will show improvement in volumetric efficiency for extremely high piston speed. Though a great lag be provided for the closing of the inlet valve, a decided drop in the volume of gas drawn into the cylinder results at high speed, owing to the friction offered at the inlet port and the restrictions of the inlet system.

Providing a great lag to the inlet-valve closing, in order to gain high volumetric efficiency at high speed, results in a great loss of efficiency when the piston is slowed down to very low speeds, for with this timing, atmospheric pressure accomplishes all it is capable of soon after the piston has passed the bottom center position. The inlet valve remaining open for a greater time results in pressure being created above the pressure induced by outer atmospheric pressure, and the gas is blown back through the open inlet valve, causing a loss in volumetric efficiency and a retarding of the velocity of the gas in the inlet manifold, which further decreases the flow of gas to other cylinders in a multi-cylinder engine. The average timing for the closing of the inlet valve provides, therefore, but a makeshift in an effort to fill the cylinder at all speeds of a very high-speed engine, as there will be but a narrow range of piston speed where the inlet valve is correctly timed, and this approximately at an intermediate speed.

The duration of the exhaust period and the time of its beginning and ending affect the volumetric efficiency, inasmuch as the rate of

fuel ejection in relation to the speed of the piston governs the condition within the cylinder before the inlet valve opens to begin a new cycle. Opening the exhaust valve slightly before bottom center at low piston speed permits the expansion to exert its force upon the piston during practically the entire travel of the piston from top center to bottom center. This timing provided for the exhaust valve being advantageous at low piston speeds would result in the retention of heat at high speeds and also a retention of carbon dioxide gas within the cylinder.

A very small quantity of carbon dioxide gas will destroy a great quantity of the fresh gas entering the cylinder, and though the former has not interfered with the volume of gas, it has destroyed some of the combustible qualities. To compensate for this condition, it would become necessary to sacrifice a great part of the inlet stroke by keeping the exhaust valve open well into the inlet stroke, and to provide a greater length of time for the heat and dead gases to be expelled. Such a closing of the exhaust valve would rob the inlet period of a large portion of the piston travel from top center, resulting in less gas being drawn into the cylinder during the shortened inlet period.

A great lead given to the opening of the exhaust valve before bottom center, while sacrificing a part of the expansion which could be used against the piston, actually gives a greater advantage, by reducing the internal pressure and cleansing the cylinder, than is gained by utilizing the expansion against the piston when traveling at very high speeds. Providing an opening to the exhaust valve 60 degrees before bottom center on the average high-speed engine insures a fairly certain scavenging of the cylinder, for the heat and dead gases are expelled while still under considerable pressure. This leaves the cylinder fairly free of pressure, heat, and dead gases by the time bottom center is reached by the piston. This lead to the opening of the exhaust valve necessitates only a few degrees lag in the closing of the exhaust valve, for there is little dead gas remaining in the cylinder for the exhaust stroke to expel.

VALVE LAPS

In the two revolutions of the crankshaft necessary to complete the four events of the four-stroke cycle, the most critical points are dead centers in a slow-speed engine and somewhat after dead centers in high-speed engines; and of the two dead centers, the most critical is the top center at the end of the exhaust stroke. It is near this position of the piston that the cycle is completed, and a new one starts with the opening of the inlet valve. This critical neutral point is reached once in two revolutions for any given cylinder; it is the position of

the piston in the cycle where the last opportunity is reached to prepare the combustion chamber for the fresh gas. Any burnt gas which has been crowded into a small space by the piston during its ascent in the exhaust stroke must be given an opportunity to escape when the piston reaches top center by holding the exhaust valve open until top center has been reached, and in many cases until after top center.

There is left within the cylinder after combustion a heavy, colorless, and odorless gas known as carbon dioxide. This gas is inert and will not permit combustion, and a small amount of this gas remaining in the cylinder after the exhaust valve closes has a telling effect upon the fresh charge.

The incomplete scavenging of the combustion chamber has created a wide diversity of opinion among designers, as to the most efficient method of timing the valves where one cycle ends and a new one starts. There is, to some extent, an agreement that the exhaust valve should not close until a few degrees after top center, for it is reasonably certain that some time should be allowed for carbon dioxide gas to find its way out the exhaust port, after it has been crowded into the smallest possible space, which occurs at the instant the piston is at the uppermost position.

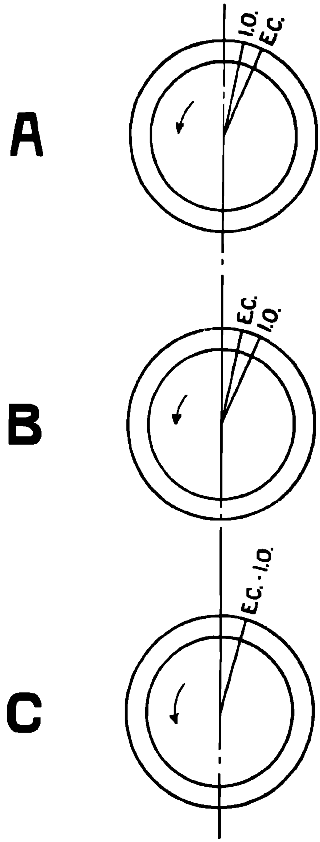


FIG. 13.—Valve Laps.

NOTE: Anti-clockwise arrows indicating timing marks are on a timing disc attached to crankshaft.

To hold the exhaust valve from its seat for any great degree of piston travel after top center has two possible drawbacks. The piston descending in the cylinder will create a slight vacuum, which may be sufficient to draw exhaust gas back into the cylinder, by counteracting the velocity given the exhaust gas by the previous up-stroke. To hold the exhaust valve from its seat for any great degree of piston travel in the inlet stroke is likewise sacrificing that much of piston travel before the inlet event can be started. This sacrifice, however, is well spent, if there is a

material gain in ridding the combustion chamber of any stray carbon dioxide.

A great sacrifice of the inlet stroke is made, by some designers, in opening the inlet valve well before the exhaust valve has closed. This practice has a tendency to create a draught through the combustion chamber, and though a small portion of piston travel on the suction stroke is lost, the loss is nothing if the objective is attained. This timing of the inlet valve opening and the exhaust valve closing is known as an *overlap*, and sometimes is called a *positive lap*. See Fig. 13.

The *overlap* has a wide variation, for the number of degrees after top center that the inlet valve opens and the exhaust valve closes has nothing to do with the term *overlap*. The inlet valve may open before top center, the exhaust valve close any number of degrees of crank travel after top center, and the timing remains an overlap. The inlet valve may open 10 degrees after top center and the exhaust valve close immediately after the inlet has opened, and the timing will still remain an *overlap*. The following are examples of overlap in popular engines:

Hornet:
Inlet opens 10 degrees before top center.
Exhaust closes 31 degrees after top center (overlap 41 degrees).

Wasp C:
Inlet opens 26 degrees before top center.
Exhaust closes 31 degrees after top center (overlap 57 degrees).

Whirlwind J–5:
Inlet opens 10 degrees before top center.
Exhaust closes 30 degrees after top center (overlap 40 degrees).

Kinner K–5:
Inlet opens 29 degrees before top center.
Exhaust closes 35 degrees after top center (overlap 64 degrees) (cold engine timing).

Under normal conditions there is much to favor a wide overlap, notwithstanding that popular opinion in the past claimed that there is likelihood of a *popping back* through the carburetor. This danger is not great, outside of theory, for a lean mixture which would cause heat to be retained will usually ignite the fresh incoming charge anyway, whether there is an overlap or not. See Fig. 13.

The usual valve-timing practice in older engines, and in a few new production engines, is to close the exhaust valve a few degrees after top center, and open the inlet valve a few degrees later. The following are examples of this valve-timing practice:

Packard Models 3A–1500 and 3A–2500:
Exhaust closes 8 degrees after top center.
Inlet opens 10 degrees after top center.

Curtiss OX–5:
Exhaust closes 5 degrees after top center.
Inlet opens $15\frac{1}{2}$ degrees after top center.

These few degrees are given the closing of the exhaust valve to allow time for the dead gases to be expelled, and the few degrees of crank travel with both valves closed are intended to permit a slight vacuum to be created within the combustion chamber before the inlet valve opens. This condition, however, is neutral in the Packard, as both valves are practically on their seats. The slight vacuum which will exist where a minus lap is used has a tendency to start the incoming charge entering with a rush, thereby compensating somewhat for the late opening of the inlet valve. Under certain conditions the vacuum may be very slight; nevertheless, a slight movement of the piston down in the cylinder, with both valves closed, will have a strong tendency to relieve any pressure existing within the cylinder.

In some engines it will be found that no lap is given either way, the exhaust valve closing and the inlet valve opening at the same instant. An example of this timing is found in the Hispano-Suiza Model A Engine, in which the exhaust valve closes 16 degrees past top center, and the inlet valve opens 16 degrees past top center.

This timing is often referred to as *zero lap*, meaning no lap at all. Where this timing is employed in an engine, it is clear that the designer did not favor keeping the exhaust valve open until the inlet valve had opened, and did not value the slight vacuum which would be created by closing the exhaust valve a few degrees before the inlet valve opened.

Another example of the zero lap timing is found in the Liberty Engine, in which the exhaust valve closes 10 degrees past top center, and the inlet valve opens 10 degrees past top center.

The Hispano-Suiza Models I and E likewise were given a *zero lap*, the exhaust valves closing 10 degrees past top center, and the inlet valves opening 10 degrees past top center.

In a few cases the *zero lap* is used at top center, that is, the exhaust valve closes at top center, where it is expected to close, and the inlet valve opens at top center at the instant the down-stroke starts. In most cases the *zero lap* will be found taking place somewhere past top center, for most designers agree that some time should be allowed for the dead gases to be expelled. Fig. 13*C*.

It is interesting to compare the difference in valve timing at this

most critical point of the cycle; and the more closely one compares the popular engines, the more one is inclined to believe that the condition at the end of the exhaust stroke is not so serious. It should not be forgotten, however, that an engine which has the exhaust valve closing and the inlet opening at top center might perform somewhat better at very high speed with later timing. If it was not the intention of the designer to bring about efficiency at high speed, he sacrificed efficiency at high speeds in order to improve the efficiency of his engine at low speeds. The designer of engines catering to those who desire speed is compelled to sacrifice low-speed efficiency in valve timing to obtain the most efficient timing for high-speed performance.

The various factors governing valve timing, aside from piston speed, make it difficult to compare different valve timings unless the comparative engines are intimately known, for a difference in the stroke and length of the connecting rod might result in seemingly different valve timing by degrees on a timing disc in comparative engines.

CONTOUR OF CAMS

The contour of the cams operating the inlet and the exhaust valves affects directly the degree of lag and lead given to the valves. This factor alone, therefore, can create a wide difference in the length of the inlet or exhaust periods, yet the same results from valve timing be obtained in comparative engines in which every other factor was equal.

A cam with a pointed nose and a contour giving a gradual opening and a gradual closing to the valve requires a longer period than one which is nearly square in its contour and gives a sudden opening, long dwell, and quick closing. The cam which gives a gradual opening and closing is still in favor, for it operates with a minimum amount of noise. This type has the disadvantage of restricting the size of the opening in a valve port, for such a form requires more time to raise the valve from the seat, holds the valve open to the maximum lift but a short interval, and starts to return the valve gradually to its seat immediately after the maximum lift. Owing to the time required in giving a sufficient opening to a valve, this form must be timed to start opening the valve fairly early, and retain the closing fairly late.

The cam having a contour resembling a square in its general contour opens a valve suddenly, gives a long dwell at maximum lift, and returns the valve to its seat suddenly. This cam is noisy in operation but provides the most efficient opening to the valve. This form of a cam, when operating an exhaust valve, releases the pressure quickly, thereby permitting the heat of combustion to be more thoroughly expelled than

in the case where a gradual opening is given, which restricts the exhaust heat somewhat by allowing it to simmer out gradually.

With the use of a square cam the exhaust period may be shorter in duration, for the average opening of the valve is greater during the interval from the time the valve starts to open until it returns to its seat. The same condition arises with the length of the inlet period when a square cam is used, and though the length of the inlet period may be less than with a pointed-nose cam, the charge of gas drawn into the cylinder will be greater, owing to the average opening of the inlet valve being greater.

The degree of lift to a valve likewise has an important bearing upon the valve timing, for a great lift offers less restriction during induction or expulsion periods, and increases the average opening of the valve in the same manner as a square cam. The lift of the valve depends upon the eccentricity of the cam nose. Greater lift than $\frac{5}{16}$ to $\frac{9}{16}$ of an inch is not in general practice, for the greater the lift the greater the resultant noise, and the designer prefers to increase the port opening by increasing the diameter of the port rather than by increasing the valve lift.

IMPORTANCE OF CORRECT TAPPET ADJUSTMENT

One of the most important adjustments on an engine is the variable clearance allowed at the valve tappets. The clearance, recommended by the manufacturer of the engine, is given only after experimenting and carefully thought-out designing. An air gap or clearance is allowed between the valve tappet and the stem of some engines to permit expansion when the valves become hot. It is obvious that if but 0.002 in. is allowed for the clearance at the tappet when the valves are cold, and the valves elongate 0.003 in. when hot, without expansion of other engine parts, the valves would be held open 0.001 in.

A riding exhaust valve soon brings destruction to the valve and the valve seat, for the heat of combustion simmers through the partially open valve, burning the face of the valve and the seat, and causing a formation of carbon at this point. In the case of the inlet valve the same destruction takes place, and more serious results may be expected, for the riding inlet valve will likewise cause continued *popping back* through the carburetor, owing to combustion leaking through the partially open valve and igniting the gas in the inlet manifold.

When the clearance of the valves is correctly adjusted according to factory recommendation, the valves will open and close exactly where the designer intended the valves to open and close after the

stems of the valves have elongated from the heat. The valves will also be opening their maximum lift, and the valve action will not be unduly noisy in operation if no abnormal wear is present in any of the parts.

Adjusting the valve tappets closer than recommended, in order to eliminate noise, causes the valves to be out of time, for they will open early and close late, and are more likely to ride upon the tappets when heated. Excessive clearance at the tappet adjustments causes the valves to open late and close early, and also decreases the lift of the valve and results in the usual noisy action.

An engine working under abnormal conditions at high internal temperatures, further aggravated by low-grade fuel, may require a greater clearance than recommended by the manufacturer. Usually the recommended clearance is given for a cold engine and should be adjusted when the engine is at normal atmospheric temperatures, unless specified to be adjusted when engine is hot.

To remove all doubt, the clearance should be checked when the engine is hot, if working under trying conditions, and, if it is found that the valves have little clearance, the clearance should be increased slightly above that recommended by the manufacturer. This condition may arise today with old engines in which ordinary gasoline is being used. The heavier fuel may cause slower combustion with a rise of internal temperatures in the engine and an abnormal expansion of the engine parts which are in contact with combustion.

Wear at the valve tappets in some engines is rapid—and the increased clearance resulting from the wear has directly a telling effect upon the power of the engine through directly putting the valves out of time. It must be realized that the crankshaft is turning at twice the speed of the camshaft; therefore, while the cams on the camshaft are taking up the excess clearance, the crankshaft has traveled double the distance. See Figs. 14 and 15.

An example might be cited in an engine with a 51½-in. timing disc. The tappets were correctly adjusted to 0.010 in.—and the timing of the valves checked on the disc. The clearance at the tappets was then increased to 0.025 in., with the result that the exhaust valve opened about 2 in. late on the timing disc and closed about the same amount early. The tappets were then adjusted to allow 0.040-in. clearance, resulting in the exhaust valve opening 3¼ in. late, or about 25 degrees. With this clearance used and the exhaust supposedly closing at top center, the valve would close 25 degrees before top center with a corresponding mistiming in the opening of the exhaust. In the case of the inlet valve, which was supposed to close 30 degrees after bottom center,

the valve closed about 10 degrees after bottom center. The effect of excessive clearance would, in this case, manifest itself in a great loss of

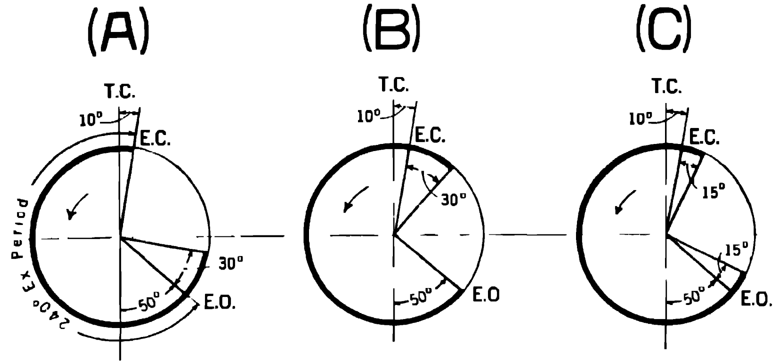


FIG. 14.—Effect of Insufficient Clearance at Valve Tappet with Three Settings of Timing Gears

(A) Gear meshed to cause exhaust valve to close correctly—opens 30 degrees early
(B) Gear meshed to cause exhaust valve to open correctly—closes 30 degrees late
(C) Gear meshed correctly results in valve opening early and closing late

NOTE Anti-clockwise arrows indicate timing marks are on a timing disc attached to crankshaft

power through the mistiming of the valves and the decreased lift of the valves. An excessive clearance of 0.030 in., while sounding exaggerated,

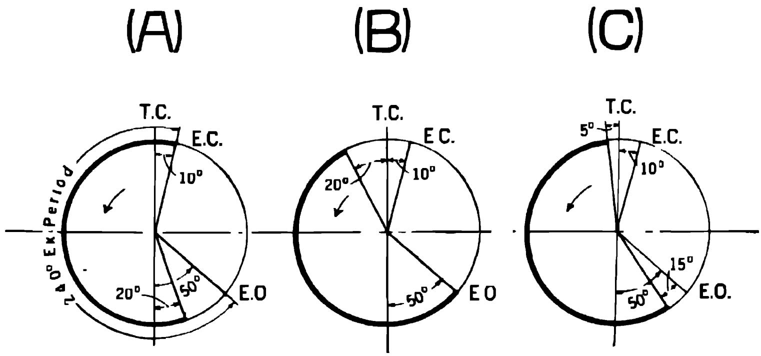


FIG. 15.—Effect of Excessive Clearance at Valve Tappet with Three Settings of Timing Gears.

(A) Gear meshed to cause exhaust valve to close correctly—opens 30 degrees late
(B) Gear meshed to cause exhaust valve to open correctly—closes 30 degrees early
(C) Gear meshed correctly results in valve opening late and closing early

is not an unusual condition in which to find tappets in a neglected engine.

In the adjusting of valve tappets some provision is often allowed for greater expansion of the exhaust-valve stem than the inlet, for the former is heated to a greater degree than the latter, which is being constantly cooled to some extent by the cool incoming gas. Usually two or three thousandths of an inch greater clearance is given the exhaust valve than the inlet valve, but quite often the same clearance is recommended for both valves. The Packard 3A-2500 Engine is an example of greater clearance being allowed the exhaust valve than is allowed the inlet. the exhaust being set 0.041 in. max., and the inlet 0.023 in. max.

Quite commonly on air-cooled aircraft engines, the expansion of the cylinder will be so great that its elongation will carry the valve and valve seat away from the valve tappet, this action tending to increase the clearance at the tappet, or, at least, compensate for the elongation of the valve stem. If the timing instructions call for setting the valves 0.050 in. on the inlet valve and 0.060 in. on the exhaust valve, as in the Hornet Engine, before attempting to time the valves, such directions are given to insure a desired timing after heat has raised the cylinders. Such instructions may be followed by additional direction to readjust valve clearances to some lesser clearance after the timing gears have been meshed and the valves timed, for instance 0.010 in., as on the Hornet Engine.

It should be obvious that an engine carrying such instructions cannot be timed with the lesser clearance, for the manufacturer has furnished directions for timing with the clearance the valves will have when cylinders are heated. The readjustment of the valves to some lesser clearance is for a cold engine setting, and, while a check of the valve timing with the cold setting will disclose an off-timing, the valves will open and close where it is desired that they open and close when the engine is hot.

During the life of an engine, there is but a single time when a slight increase in the tappet clearance, over that recommended, is advisable. This condition arises with a new engine which has not been "worked in" and in which the cams and followers and tappet guides have not become polished from contact. No matter how smooth the surface of the cam, cam follower, tappet, and tappet guide may appear to the eye or touch, a microscopic view will disclose a rough surface.

To facilitate a rapid polishing of the valve-lifting mechanism parts, a perfect lubrication must be maintained, or the rough surfaces will tear at each other and prevent the desired polish from ever being attained. To lubricate thoroughly these surfaces during the polishing stage, a thick film of oil must be maintained upon the surfaces, by having

a tappet clearance which is excessive enough to prevent any possible dragging of the cam follower over the cam when the valve elongates from heat. This precaution is necessary only for those engines requiring a close tappet adjustment for correct valve timing.

It should be clearly understood that the recommendation for slightly excessive clearance at the valve tappets applies only to those engines operating *normally with a few thousandths* of an inch clearance, and only to the time when the engine is being "run in" on the block. Those engines which have a large normal valve-tappet clearance with a further increase of clearance when hot need no excessive clearance at any time during service.

TIMING BY DISC AND KNOWN TAPPET CLEARANCE

An engine carefully timed at the factory, with the timing gears clearly marked, will cause no difficulties in recovering the original valve timing after the engine has been taken apart for repairs. However, this condition is not always found by the mechanic when working on old engines. Engines which have been worked upon by many mechanics are likely to have a mark upon the timing gears for each workman who removed the timing gears, making the marks indicate nothing to the unfortunate who is called upon to assemble an engine which he did not disassemble.

Too much reliance has been placed in distinguishing marks upon timing gears, and the result has been that many workmen have remained in ignorance of any method of timing the valves without such distinguishing marks. The conditions possible in timing the valves without marks on the timing gears are many. The most favorable condition would be the one where a timing disc is available bearing marks for the opening and closing of the valves, and the clearance at the tappets is known. With a marked timing disc and the tappet clearance known, the following procedure should be followed:

First.—The workman should secure the timing disc in its correct position by placing its top center mark 1 and 4 directly under the trammel when 1 and 4 pistons are on top center if the engine is a four-cylinder, or the pistons 1 and 6 at top center in the case of a six-cylinder, the same method to be followed on one block in the case of an eight-cylinder V-type or a twelve-cylinder V-type. The timing disc correctly attached to the crankshaft will show corresponding marks pointing to the trammel; that is, a mark representing top center 1 and 4 or 1 and 6 will be directly opposite the trammel.

Second.—The clearance at one particular valve of either cylinder

1 or 4, or 1 and 6 should be carefully adjusted to the clearance recommended by the manufacturer. The exhaust or inlet valve tappet of either cylinder may be chosen. Customarily the exhaust valve tappet of No. 1 cylinder is used for timing the camshaft.

Third.—With the correct clearance at the valve tappet of No. 1 exhaust valve, the mark upon the timing disc, representing the position where the exhaust valves 1 and 4 close, is placed under the trammel. The piston will then be in the correct position for the exhaust valve of either No. 1 cylinder or the exhaust valve of No. 4 cylinder to close.

Fourth.—The camshaft should now be rotated by hand in the direction it rotates when engine is running, which will be opposite the crankshaft when driven by a gear without the use of an idler gear. Continue to turn the camshaft in the correct direction until the exhaust valve opens wide and is closing. When the position is reached where the valve returns to its seat and there is again a slight clearance at the tappet, the camshaft gear should be engaged with the crankshaft gear. Care should be used to prevent further turning of the camshaft in either direction during the engagement of the timing gears. This is not always possible where helical-cut timing gears are used. In meshing these gears a slight turning of the camshaft may result. This need not bother the workman, for the timing will not be out more than one tooth on the gears and can readily be checked by turning the crankshaft two revolutions and noting whether the exhaust valve of No. 1 cylinder closes exactly when the timing mark is under the trammel.

If it is found, in checking the timing, that the valve closes late or closes early, the timing gears may be marked with a pencil or chalk, and the camshaft gear set ahead one tooth in the direction of rotation if the valve closed late, or moved back one tooth if the valve closed early. The closing of the exhaust valve should again be checked by further revolving of the crankshaft, and if the clearance at the valve tappet is correct, the valve will close within two degrees of the closing mark, and will open within two degrees of the opening mark.

Fifth.—The camshaft is now correctly timed, and No. 1 exhaust valve is correctly timed. To complete the valve-timing operation it is necessary only to adjust the remaining valve tappets to the correct clearance. This can best be done by adjusting any tappet, whether inlet or exhaust, which is riding upon the heel of its cam. A simple method of determining the position of the cam for any particular valve is to note whether its mate for that cylinder is open. For instance, if the clearance of No. 1 inlet tappet is to be adjusted, it is necessary only to turn the engine by hand until the exhaust valve for No. 1 cylinder is open wide. The inlet cam for this cylinder will then be in the opposite position; therefore, all doubt is removed as to the likelihood of the

inlet valve being held slightly open by the cam. This inlet tappet should then be marked to indicate that its clearance has been adjusted, and the engine turned until other valves are open wide and their mates adjusted. A few turns of the engine will suffice to adjust all the tappets. This method is practiced by some while others use the method of placing No. 1 piston upon firing top center where both valves are closed, and, after adjusting the tappets for that cylinder, turning the crankshaft until the next cylinder, in order of firing, is at firing top center etc.

TIMING BY PISTON TRAVEL AND KNOWN TAPPET CLEARANCE

The valves of an engine may be timed by another method, which does not call for the attaching of a timing disc. Instructions governing the opening and closing of the valves in relation to the position of the piston in the cylinder may be furnished by the manufacturer. This is called *tramming the engine by piston travel.* Instead of setting a timing disc so that the marks for top centers 1 and 4 are opposite the trammel or at any position where a valve opens or closes, the position of the piston in its travel is noted and set according to the instructions. If the exhaust valve is to close $\frac{1}{8}$ in. after top center of piston travel, the clearance of No. 1 exhaust valve tappet must be correctly adjusted and the piston placed $\frac{1}{8}$ in. after absolute top center and the camshaft gear engaged with the crankshaft gear.

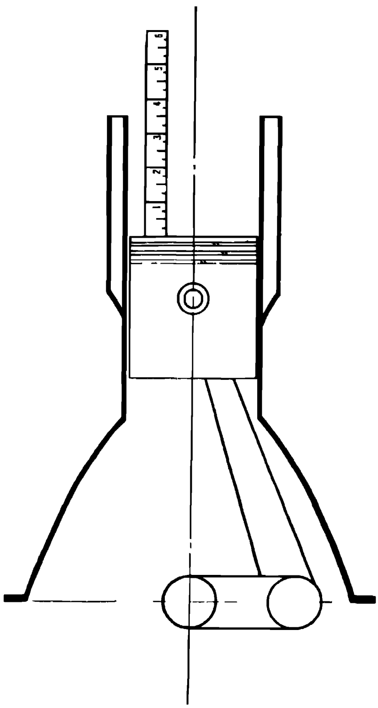


Fig. 16.—Timing by Piston Travel.

Often some trouble is experienced in timing the valves by this method, owing to the difficulty in determining exactly $\frac{1}{8}$ in. of piston travel after absolute top center. The difficulty arises from the stopping of the piston at top center while the crankshaft continues to move. To insure an accurate position of the piston, most manufacturers give the exact position the piston will be in the stroke when measured from some surface on the cylinder; for instance, the measurement may be given from the top of the cylinder when the cylinder head is removed. See Fig. 16.

Where a piston extends $\frac{1}{8}$ in. above the flush position of the cylinder, the manufacturer's instructions are to set the piston flush with the cylinder if the exhaust valve closes $\frac{1}{8}$ in. after top center. If the timing of the exhaust was to be done by the opening of the valve, the instructions would read: "Exhaust valve opens $\frac{1}{2}$ in. before bottom center or $4\frac{3}{8}$ in. from the top of the cylinder." From this it is obvious that the exhaust valve will open $4\frac{1}{2}$ in. after top center, owing to the $\frac{1}{8}$ in. to be added for the travel of the piston above the flush of the cylinder, and that the stroke of the piston is 5 in.

In the case of the exhaust valve closing exactly at top center—and any difficulty being experienced in determining when the piston is at absolute top dead center—the point may readily be found by placing the piston some position before top center; for instance, $\frac{1}{4}$ in. before the piston is flush with the top of the cylinder. With the piston in this position place a mark upon the propeller hub on a center line with the cylinder block. Next, place the piston $\frac{1}{4}$ in. after the flush position, or, in other words, on the next down-stroke, and mark the propeller hub again on a center line with the cylinder block. Midway between the two marks on the propeller hub will be the absolute dead center of the piston, which can readily be found with either a pair of dividers or a flexible rule. At the best, timing of the valves by piston travel is difficult, and there are more chances of error than when timing with a disc.

TIMING BY DISC MARKS AND UNKNOWN TAPPET CLEARANCE

Where a marked timing disc is available to indicate the position of the crankshaft when the valves are to open and close, the marks serve as a guide, and are all the information necessary to time the camshaft and adjust the clearance at the valve tappets. In a shop where strange engines are brought for repairs, it might happen that there would be opening and closing marks upon a timing disc, but the factory recommendation for the adjustment of the valve tappets be unknown.

After determining whether the timing disc is correctly attached, the following procedure should be carried out:

First.—Choose an inlet or exhaust valve of No. 1 or No. 4 cylinder and adjust the tappet until it has an average clearance.

Second.—Set the crankshaft in a position where the exhaust closing mark for 1 and 4 is under the trammel. Turn the camshaft in the correct direction of its rotation until the exhaust valve has opened, and continue rotating the camshaft until the position is reached where

the exhaust valve returns to its seat and a slight clearance is recovered at the tappet. The camshaft gear should then be meshed with the crankshaft gear and the crankshaft turned two revolutions to ascertain whether the exhaust valve returns to its seat at the instant the closing mark on the disc comes under the trammel. When the position of the camshaft gear has been found where the exhaust valve will close correctly, the crankshaft should be rotated in the correct direction until the exhaust valve just starts to open, which is the instant the clearance at the tappet is taken up and the tappet touches the valve stem lightly.

Third.—When the position is found where the exhaust valve starts to open, a mark must be placed upon the timing disc with a pencil or chalk to represent this position of opening. If the clearance given the tappet is greater than the engine designer intended it to be, the new mark on the disc will be found to be later than the mark on the disc which indicates where the exhaust valve is supposed to open. This is caused by the excessive clearance shortening the length of the exhaust period.

There will now be two marks on the timing disc, one the correct mark and the pencil mark indicating where the valve does open. The exact center between these marks should be found, and a third mark placed on the disc at this point. The disc must then be placed upon this new mark and the valve tappet adjusted so the tappet lightly touches the valve stem. The exhaust valve would then be opening at this new mark, and further checking would show that it was now closing late; therefore the proper duration has been reached, but the camshaft is out of time.

Fourth.—Remove the camshaft gear and again place the disc exhaust closing mark under the trammel and time the camshaft with the new tappet adjustment. If care has been used, the exhaust valve will be found to open correctly and close correctly.

If the clearance at the tappet which was given by guess was too close instead of too great, the exhaust period would have been lengthened instead of shortened, but it can readily be corrected by following the same method of marking the disc as explained for excessive clearance.

TIMING WITHOUT INSTRUCTIONS AND UNKNOWN TAPPET CLEARANCE

It is a rare occurrence that a workman is called upon to time the valves of an engine without any instructions to guide him. This situation, however, may arise in isolated districts where correct information is difficult to obtain quickly. While guesswork in timing valves

on aircraft engines cannot be too strongly condemned, for the sake of a better understanding of valve timing the following method of timing without information is suggested:

First.—It is necessary under these circumstances to adjust the valve tappets so that their clearance will provide a duration of the exhaust and the inlet periods of sufficient length for high-speed work. If the engine is water-cooled a clearance of 0.010 in. should be tried unless it is known that the engine is one which operates at very high temperatures. In the case of high internal engine temperatures being anticipated the clearance should be increased.

Second.—It next becomes necessary to decide upon the position of the piston where the exhaust or inlet period is to start and end. Comparing the average opening and closing of the exhaust valves of various engines, there is found a great difference in extreme cases when the opening of the exhaust valve is considered. Some engines open the exhaust valve 35 degrees before bottom center of crank travel, whereas in others the lead may be as much as 70 degrees before bottom center. The difference in the closing of the exhaust valve of various engines is not great, the closing taking place between top center and 20 degrees after top center. Except in a few cases, the closing of the exhaust valve takes places approximately 10 degrees past top center. This position should be chosen and the camshaft gear meshed with the crankshaft gear.

Third.—The crankshaft should then be rotated in the correct direction and the critical point observed, that is, the inlet valve opening should be checked, and the instant of its opening marked upon the disc or propeller hub. If it is found that the inlet valve opens before top center, in most cases this will indicate that the timing is too early, though there are engines in which the inlet valve opens before top center, as previously explained. If the inlet valve is found to open 25 degrees after top center, the timing is too late, and the exhaust valve should be closed nearer top center to bring the opening of the inlet valve within a more reasonable opening. If the valves are found to have an overlap of a few degrees, the opening of the inlet and the closing of the exhaust should be set to take place between top center and 15 degrees past top center for a trial. If it is found that the valves have an overlap of from 30 to 50 degrees, the overlap should be divided about evenly on each side of top center, in order to arrive at the average valve timing when great overlaps are allowed.

Averaging the closing of the exhaust valve and the opening of the inlet valve near 10 degrees past top center is more than likely to let one arrive near the correct timing on all engines which do not have great overlaps.

Fourth.—After a decision has been made as to the intended closing of the exhaust valve and the opening of the inlet valve, the camshaft gear may be meshed and the opening of the exhaust and the closing of the inlet checked in order to learn whether these timings appear to fall within reasonable practice. If these settings are found to be within reason, the engine should be started and run until it is thoroughly heated. The engine should then be stopped so the valve tappets may be checked for possible riding. If the clearance is still sufficient at the tappets, the engine should again be started and throttled down to a very slow speed. While running at a throttled speed the inlet of air through the main air opening of the carburetor should be noted; a pronounced blowing back indicates that the inlet valve is closing too late. This condition can be corrected by retiming the camshaft so that the inlet valve opens sooner.

If the correct timing has not been recovered, the engine will not turn up its maximum revolutions per minute, yet if good judgment has been used in the timing at the neutral point the camshaft will not be out of time more than one tooth. A little experimenting with a tooth each way on the camshaft gear will quickly secure the timing which will bring the engine speed up to maximum. If a verification of the timing is sought and cannot be obtained in full detail, it should be remembered that, with the correct tappet clearance known, it will be necessary to have but the closing of the exhaust valve or the opening of the exhaust valve or the same information regarding the inlet valve in order to time the valves without error or guesswork. With the correct tappet-clearance information unattainable, it becomes necessary to know the opening and closing of either the exhaust valve or the inlet valve to learn the correct tappet clearance.

EFFECT OF PISTON TRAVEL UPON VALVE TIMING

There is one factor governing valve timing seldom considered except by the designers of engines. This factor is the variable speed of the piston during each stroke while the crankshaft is rotating at a constant speed. The increasing angularity of the connecting rod from top center to 90 degrees of crankpin travel draws the piston farther down in its stroke than the second 90 degrees of travel during which time the angularity of the connecting rod is decreasing. See Fig. 17.

The diagram of "Piston Travel" shows the relative position of the piston and the crankpin during 180 degrees of crank travel from top center to bottom center. The stroke of the piston from top center to bottom center is divided into 180 equal parts, to correspond to the number of degrees of crank travel.

The diagram represents a piston having a 6-in. stroke and a 12-in. connecting rod. During the first quarter of the revolution of the crankpin, which is to the position of the greatest angularity of the connecting rod, the piston has traveled approximately 100 of the 180 equal parts on the scale representing the piston travel, while the crankpin has traveled only 90 degrees. Measured in inches, the piston has traveled $3\frac{1}{4}$ in. of the 6-in. stroke, a gain of $\frac{1}{4}$ in. during the first quarter of a revolution of the crankpin. During the travel of the crankpin from the first 90-degree position to the 180-degree position, or bottom center, the piston has to move but $2\frac{3}{4}$ in. Therefore, it is obvious that the speed of the piston must decrease with the crankpin rotating at a uniform speed.

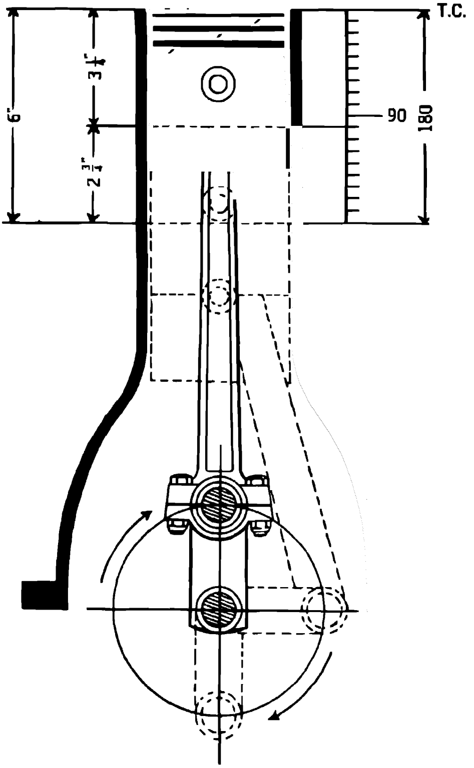


FIG. 17.—Effect of Piston Travel First and Second Quarters

It should be clear from a study of the diagram that the piston during the first 90 degrees of crankpin travel will be drawn down in the cylinder half the length of the stroke plus the distance the piston is drawn down in the cylinder by the connecting rod angularity in reaching the extreme angularity when the crankpin is at the 90-degree position.

The distance the piston is drawn down in the cylinder will vary with different proportions of stroke length to connecting rod length. With a 12-in. connecting rod and an 8-in. stroke, the piston travel the first quarter revolution of crank will be $4\frac{1}{2}$ in. and but $3\frac{1}{2}$ in. the second quarter. With the same stroke of 8 in. and an 8-in. connecting rod, the piston would travel 5 in. the first quarter and 3 in. the second quarter.

From the foregoing it will be apparent that the longer the connecting

rod for any given stroke, the less angularity to the connecting rod, with a corresponding decrease in the variation of the piston speed the first quarter in relation to the second quarter. Therefore, with the piston running closer to a uniform speed throughout the stroke, there will be less vibration. In all cases in which there is any considerable difference of piston travel in relation to crank travel the first quarter to the second quarter, and from the third quarter to the last quarter, the valve timing will be affected when reckoned in degrees of crank travel. For every degree of crank travel after top center there is a greater movement of the piston up to 90 degrees than there is for every degree of piston travel after 90 degrees and up to the 270-degree position, or three-quarter turn of the crank.

Aside from the interesting aspect of this phenomenon, it has no value in practical work. Yet it leads to a clearer understanding of the subject. The variable speed of the pistons during each stroke also accounts for the alternate vacuum and pressure in the crankcase of an engine. In a four-cylinder engine there are two pistons ascending while two are descending, but as the movement of the descending pistons is faster during the first half of the stroke than the movement of the ascending pistons, a compression results in the crankcase. During the second half of the stroke, the descending pistons slow down while the ascending pistons move faster. Therefore a slight vacuum is created in the crankcase.

To prevent a compression and vacuum of any great degree, the well-known *breathers* are placed in the crankcase. The compression is released through the breathers during the time the pistons would create a crankcase pressure, and this serves the double purpose of preventing any opposition against the pistons and also forces out heat from the crankcase. During the time when there is a tendency for the pistons to create a slight vacuum in the crankcase, atmospheric pressure enters through the breathers, carrying cool air into the crankcase, preventing any great vacuum forming, and opposition to the ascending pistons is prevented.

TIMING THE VALVES OF THE PRATT & WHITNEY HORNET ENGINE

To time the valves of the Pratt & Whitney Hornet A-1 Engine, have the thrust-bearing cover off and slack off the thrust-bearing nut two or three turns. Set the valves of No. 1 cylinder with 0.050-in. clearance on intake and 0.060 in. on exhaust, being sure that the cam is at the lowest point when this is done. (The timing disc should have the following marks: Inlet opens 10 degrees early, Inlet closes 60 de-

grees late, Exhaust opens 71 degrees early, Exhaust closes 30 degrees late.) This clearance is for timing only. Use a valve-clearance gage. When testing the valve clearance, the feeler is inserted between the valve stem and the valve-adjusting screw ball. The valve rocker must be lifted up hard enough to overcome a spring in the tappet. Slightly separate the teeth of the cam hub sleeve and the thrust-bearing sleeve. This can be done by removing the front breather, inserting a screw-driver through the breather hole, and using it to pry the sleeves apart.

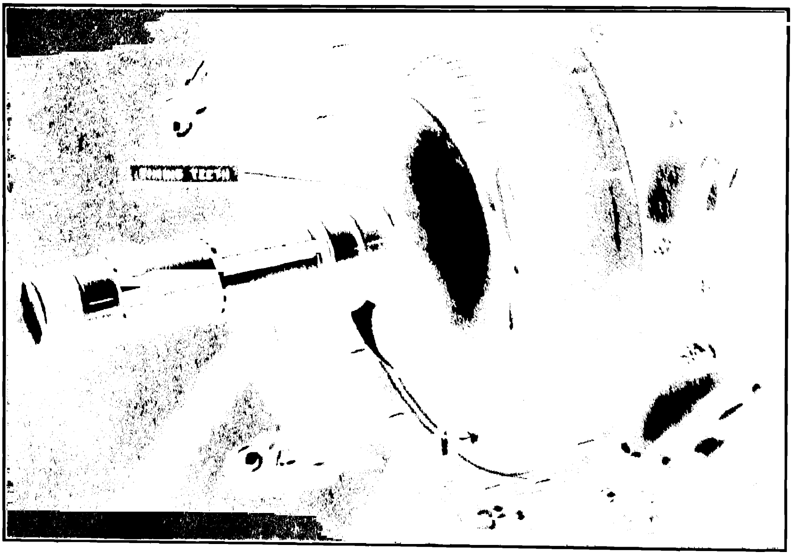


FIG. 18 – Hornet Engine with Front Section of Crankcase Removed, Showing the Cam Drive Clutch Disengaged

After the engine is assembled and the valves are timed the teeth shown are held tightly together by the thrust bearing nut

Attach the timing disc to the front of the crankcase so that the top center mark is in line with No. 1 cylinder. If no timing disc is at hand, use the marks on the face of the crankcase front section. These will be seen when the thrust-bearing cover is removed. Take out the screw plug near the front breather and insert the timing wrench so that its teeth engage the intermediate gear. Fasten a pointer to the crankshaft or propeller hub so that when No. 1 cylinder is on top dead center the pointer will register with the dead-center mark on the timing disc.

Turn the crankshaft counter-clockwise until the pointer comes to the inlet opening mark. Then turn the timing wrench counter-clockwise

Wrong Way

Right Way.

FIG. 19.—Checking Valve Clearances.

until the inlet valve clearance is just taken up, the valve being about to open. Next, screw up the thrust-bearing nut. Look through the breather hole and make sure that the teeth on the two sleeves are

FIG. 20. A Timing Disc Applied to a Hornet Engine.

engaged and not riding on the tops of each other. After tightening the nut, check the inlet opening and exhaust closing again, when turning the shaft slowly in the normal direction (counter-clockwise as seen from the front). After checking the timing, reset the clearance of both valves to 0.010 in. and see that the clearance of valves of the other cylinders is properly set to 0.010 in.

TIMING THE VALVES OF THE WARNER SCARAB ENGINE

To time the valves of the Warner Scarab Engine, turn the idler shaft to get the valves in cylinder No. 1 in the position corresponding to firing top center, in which position both valves of this cylinder are fully closed, while No. 7 intake and No. 2 exhaust valves are both half way open. Set both rocker arms of cylinder No. 1 to a tappet clearance of 0.027 in. Attach the timing-disc assembly and wrench with the propeller nut to the crankshaft. The key on the crankshaft taper is machined exactly opposite the crank throw, so that if the graduated disc is once set exactly on the timing-disc hub, this setting is good for all engines. Attach the reading pointer which goes with the timing-disc assembly to the front studs of cylinder flange No. 1.

Set the disc to 10 degrees before top center and slowly turn the idler shaft by means of the oil pump coupling, anti-clockwise, until the intake valve starts to open. This is easily checked by inserting a 0.0015-in. feeler between the valve stem and the rocker arm roller. As soon as the feeler begins to stick, place the idler-shaft gear on the hub, and attach it with three cap screws where the holes in the gear

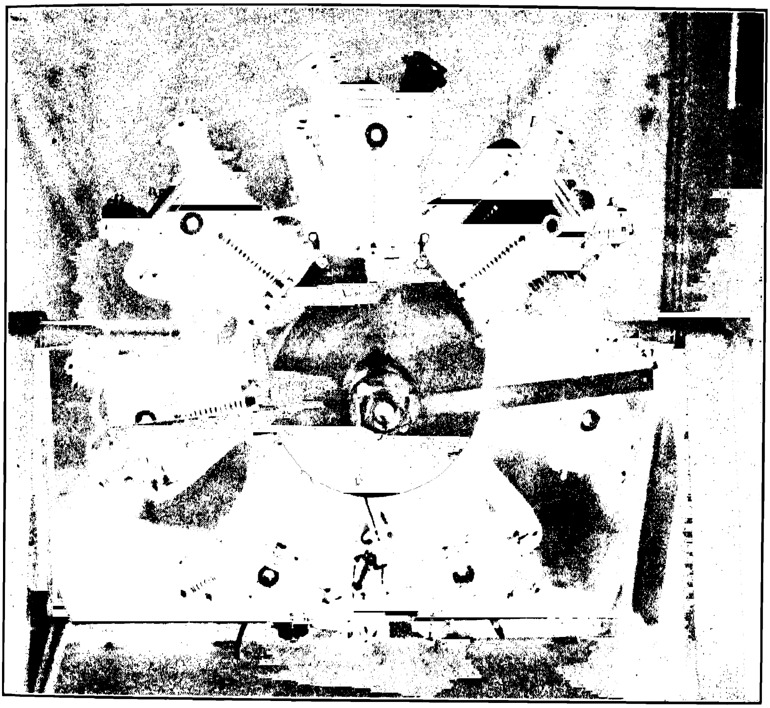


FIG. 21.—A Timing Disc Applied to a Warner Scarab Engine.

match those in the hub. Neither the idler shaft nor the auxiliaries drive shaft should be turned when this is done.

Next, check the timing of all four cam lobes to the following values, using a 0.027-in. feeler.

Intake opens 10 degrees before top center.
Intake closes 60 degrees after bottom center.
Exhaust opens 60 degrees before bottom center.
Exhaust closes 10 degrees after top center.

Each two full turns of the crankshaft bring the next cam lobe in

contact with the valve gear. If in checking it is found that the timing does not correspond to the above figures, check the tappet clearance,

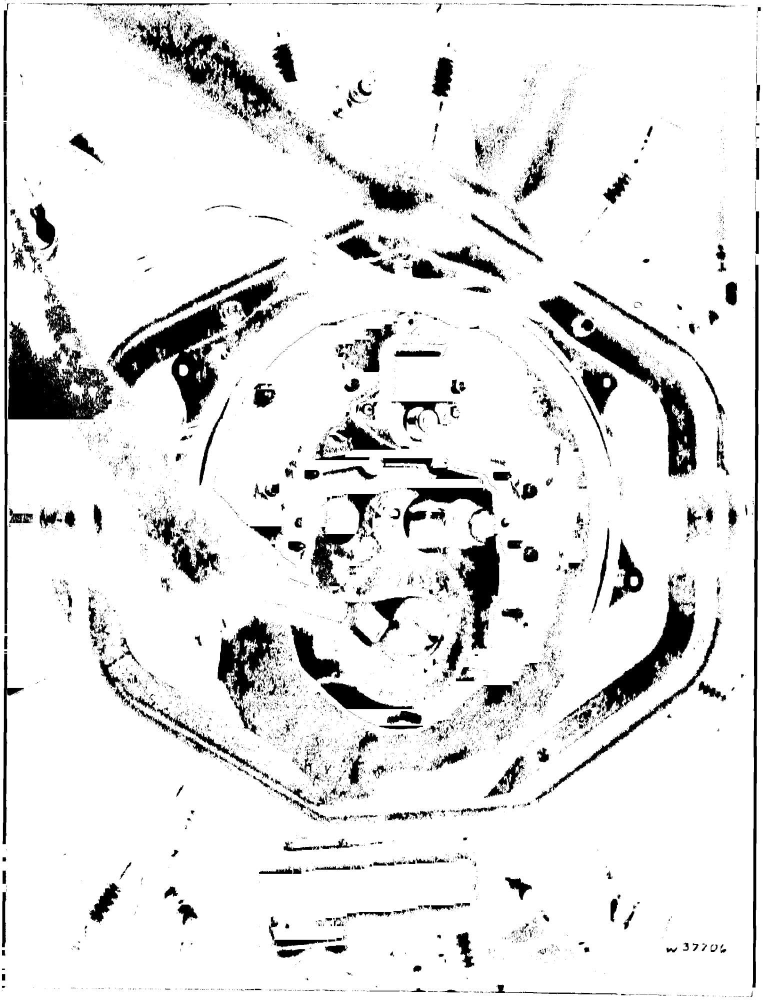


FIG 22—Timing the Valves of the Warner Scarab Engine

Rear view showing how the valves are timed by turning the idler shaft while a 0.0015" feeler gage is inserted between the rocker arm roller and valve stem—the 3 cap screws having been removed from the idler gear.

which must be exactly 0.027 in. If the trouble is not in the tappet

clearances, remove the three cap screws holding the timing gear to the hub, and attach the gear to the hub in such a way that the intake valve closes as nearly as possible to 60 degrees after bottom center. It will then be found that all the other timing values will be within three degrees of the values given in the table, this slight variation being due to the limits in machining. Do not forget to lockwire the cap screws after the timing is finished, and to set all tappet clearances to 0.010 in., while the engine is cold. This will result in a tappet clearance of approximately 0.027 in. when the engine is warm.

SUMMARY OF POINTS ON VALVE TIMING

Point 1.—When a valve is purposely opened or closed late, this action is referred to as *valve lag.*

Point 2.—When a valve is purposely opened or closed early, this action is referred to as *valve lead.* However, there is no *lead* to the closing of any valve in an internal-combustion engine.

Point 3.—Low-speed internal-combustion engines have less valve lag and valve lead than high-speed engines.

Point 4.—To provide a valve timing suitable for the variable speed of the engine, an average timing between low-speed timing and high-speed timing is given. Therefore, some engines are more efficient at certain speeds when they are operating near the most efficient valve timing.

Point 5.—An excessive clearance between valve tappet and valve stem or push rod causes the valve to open late and close early, thereby shortening the duration of the event.

Point 6.—Too close an adjustment between valve tappet and valve stem or push rod causes the valve to open early and close late, thereby lengthening the duration of the event.

Point 7.—When the correct clearance between the valve tappet and valve stem or push rod is known, the valves may be timed on all engines having one camshaft if either the opening or the closing of either an exhaust or an inlet valve is known.

Point 8.—When the correct clearance between the valve tappet and valve stem or push rod is not known, it is necessary in order to time the valves to know the position of the opening and the closing of either an exhaust or an inlet valve.

Point 9.—When a valve is found to open early and close early the same number of degrees on the timing disc, the clearance at the valve tappet is correct but the camshaft is out of time; or when a valve opens late and closes late the same number of degrees, the tappet is correct, but the camshaft is out of time.

Point 10.—When a valve is found to open late and close early the same number of degrees the camshaft is correctly timed, but the valve tappet has an excessive clearance.

Point 11.—When a valve is found to open early and close late the same number of degrees, the camshaft is timed correctly, but the clearance at the valve tappet is insufficient.

Point 12.—If a valve is found to close upon its mark but opens early or late, both the camshaft and the clearance at the valve tappet are wrong, and the same is true when a valve is found to open correctly and close early or late.

Point 13.—It may be necessary to allow a different clearance at the valve tappets for the inlet valves when the exhaust valves are used for timing, because of some engines being designed for greater clearance for the exhaust valve tappets to allow for the increased expansion from higher temperature.

Point 14.—Some air-cooled engines are given a large valve clearance for timing purposes, and are then reset to a lesser clearance for running. In other words, the valves are set at the hot clearance, the valves timed, and then reset to the cold clearance.

TABLE OF VALVE TIMINGS

Pratt & Whitney Hornet

Inlet opens 10 degrees before top center.
Inlet closes 60 degrees after bottom center.
Exhaust opens 71 degrees before bottom center.
Exhaust closes 31 degrees after top center.
Timing valve clearance, 0.050-in. inlet; 0.060-in. exhaust.
Running clearance (cold), 0.010 in.

Pratt & Whitney Wasp, Series B and Series C

Inlet opens 26 degrees before top center.
Inlet closes 76 degrees after bottom center.
Exhaust opens 71 degrees before bottom center.
Exhaust closes 31 degrees after top center.
Timing clearance, 0.060 in. for inlet and exhaust, with $\frac{9}{16}$-in. inlet valve lift. 0.050-in. inlet clearance for $\frac{11}{16}$-in. inlet lift.
Running clearance (cold), 0.010 in.

Wright Whirlwind J-4A; J-4B; J-5

Inlet opens 8 degrees before top center.
Inlet closes 60 degrees after bottom center.
Exhaust opens 60 degrees before bottom center.

Exhaust closes 8 degrees after top center.
Timing valve clearance, 0.060-in. inlet and exhaust.
Running clearance (cold), 0.010 in.

Wright Whirlwind J-6 Series, Nine, Seven, and Five Cylinders

Inlet opens 10 degrees before top center
Inlet closes 60 degrees after bottom center
Exhaust opens 75 degrees before bottom center
Exhaust closes 30 degrees after top center
Timing valve clearance, 0.070-in. inlet and exhaust.
Running clearance (cold), 0.010 in.

Kinner K-5

Inlet opens 29 degrees before top center.
Inlet closes 81 degrees after bottom center.
Exhaust opens 75 degrees before bottom center.
Exhaust closes 35 degrees after top center
Timing valve clearance, 0.020 in. (engine cold).
Running clearance (cold), 0.020 in.

American Cirrus

Inlet opens 12 degrees before top center
Inlet closes 70 degrees after bottom center
Exhaust opens 70 degrees before bottom center
Exhaust closes 28 degrees after top center
Valve clearance (cold) inlet, 0.005 in., exhaust, 0.020 in.

Warner Scarab

Inlet opens 10 degrees before top center
Inlet closes 60 degrees after bottom center
Exhaust opens 60 degrees before bottom center
Exhaust closes 10 degrees after top center
Timing valve clearance, 0.027-in. inlet and exhaust
Running clearance (cold), 0.010 in.

Curtiss D-12

Inlet opens 5 degrees before top center
Inlet closes 35 degrees after bottom center
Exhaust opens 55 degrees before bottom center
Exhaust closes 10 degrees after top center
Valve clearance (cold), 0.014 to 0.016-in. inlet and exhaust.

Packard 3A–1500 and 3A–2500

Inlet opens 10 degrees after top center.
Inlet closes 45 degrees after bottom center.
Exhaust opens 48 degrees before bottom center.
Exhaust closes 8 degrees after top center.
Valve clearance, model 3A–1500, inlet, 0.020 to 0.023 in.; exhaust, 0.020 to 0.023 in.
Valve clearance, model 3A–2500, inlet, 0.025 to 0.028 in.; exhaust, 0.038 to 0.041 in.

Curtiss OX-5

Inlet opens 15½ degrees after top center.
Inlet closes 40 degrees after bottom center.
Exhaust opens 48 degrees before bottom center.
Exhaust closes 5 degrees after top center.
Valve clearance, 0.010 in. (cold).

Liberty 12

Inlet opens 10 degrees after top center.
Inlet closes 45 degrees after bottom center.
Exhaust opens 50 degrees before bottom center.
Exhaust closes 10 degrees after top center.
Valve clearance (cold) inlet, 0.014 to 0.016 in.; exhaust, 0.019 to 0.021 in.

LeBlond Sixty and Ninety

Hot Engine:
Inlet opens at top center.
Inlet closes 60 degrees after bottom center.
Exhaust opens 60 degrees before bottom center.
Exhaust closes at top center.
Valve clearance (cold), 0.015-in. inlet and exhaust.
Valve clearance (hot), 0.035-in. inlet and exhaust.

Axelson A

Inlet opens 8 degrees before top center.
Inlet closes 60 degrees after bottom center.
Exhaust opens 60 degrees before bottom center.
Exhaust closes 8 degrees after top center.
Valve clearance (hot or cold), 0.015 in. for inlet and exhaust.

Hispano–Suiza

Inlet opens 16 degrees after top center.
Inlet closes 83 degrees after bottom center.

Exhaust opens 75 degrees before bottom center.
Exhaust closes 16 degrees after top center.
Valve clearance (cold), 0.0787-in. inlet and exhaust.

Curtiss Challenger, Model R-600

Inlet opens 24 degrees before top center.
Inlet closes 51 degrees after bottom center.
Exhaust opens 67 degrees before bottom center.
Exhaust closes 4 degrees after top center.
Valve clearance (cold) inlet, 0.005 in.; exhaust, 0.010 in.

CHAPTER III

FIRING ORDERS

Four-cylinder firing orders are limited to two in number, with the conventional practice of arranging the crank throws 1 and 4 opposed to the crank throws 2 and 3. With this arrangement, when pistons 1 and 4 are upon top dead center, the pistons 2 and 3 are at bottom dead center. If the crank throws were arranged so that the pistons 1 and 3 were paired and opposed to 2 and 4, the firing order would be 1, 2, 3, 4. This firing order would result in excessive vibration because of the surging of power impulses from one end of the engine to the other.

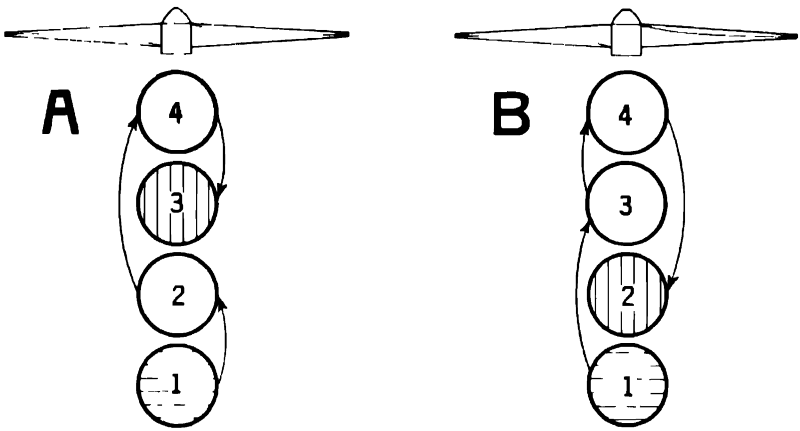


FIG. 23 The Two Possible Four-cylinder Firing Orders.

The orthodox practice of arranging the crank throws 1 and 4 opposed to the crank throws 2 and 3 makes possible two firing orders: 1, 2, 4, 3 and 1, 3, 4, 2. Neither of these firing orders has any superiority over the other, and any universal adoption of either firing order will be for the sake of standardization. These two firing orders have equal value in reducing vibration, to the extent that vibration can be reduced in a four-cylinder engine.

EIGHT-CYLINDER V-TYPE ENGINE

With a correct understanding of the two possible firing orders for a four-cylinder engine, the firing orders possible in an eight-cylinder V-type engine become simple, for the so-called eight-cylinder V-type engine is nothing more than two four-cylinder engines coupled to a single four-cylinder crankshaft.

Regardless of how confusing the firing order of an eight-cylinder V-type may appear, the point should not be lost sight of that each

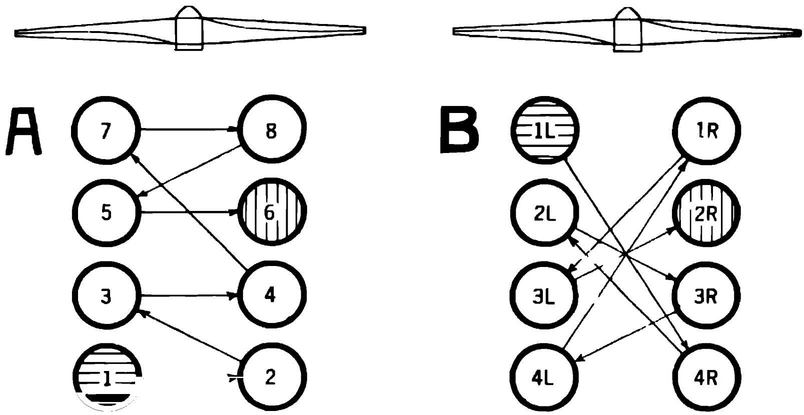


FIG. 24. – Two Applications of the Firing Order 1, 2, 4, 3.

(A) The Curtiss OX-5 Engine
(B) The Hispano-Suiza Engine

block, or bank of cylinders, has but two possible firing orders, the same as a four-cylinder: 1, 2, 4, 3 or 1, 3, 4, 2.

In the absence of any firing-order instructions, any visible numbering of the cylinders may be ignored, and the firing order of each block, or bank of cylinders, determined by noting the action of the valves. If the firing order is found to be 1, 2, 4, 3 upon one block, or bank of cylinders, it does not necessarily follow that the firing order will be 1, 2, 4, 3 on the opposite cylinders, for 1, 3, 4, 2 is a possible order, though the common practice is to use the same firing order on both blocks, or banks of cylinders.

After the firing order of the opposing sets of cylinders is known, it becomes necessary to determine whether the firing occurs from the front to the rear alternately on each block, as in Fig. 24*A*, or from the front to the rear on the left block and rear to the front on the right block, as in Fig. 24*B*, though the latter is the favored method in most

cases. The Curtiss OX-5 eight-cylinder V-type engine employs the firing order and cylinder numbering shown in Fig. 24*A*.

Once the order in which all eight-cylinders fire is learned and their rotation marked, the wires to the spark plugs from the distributor may be connected by starting with any cylinder of the eight. With any piston on *firing* top center, the wires from that particular spark plug should be connected with the segment of the distributor to which the rotor of the distributor is pointing, and the remaining wires connected according to the firing order, care being taken to note the direction of rotation of rotor in the distributor. For instance, if the firing order is found to be the same as in Fig. 24*A* (Curtiss OX-5), and the engine happens to be upon firing top center on No. 5, whatever segment of the distributor the rotor is on must be connected to the spark plug of No. 5, and the remainder wired 6, 7, 8, 1, 2, 3, 4. It should be clear from this that it is not necessary to start with No. 1, for in an unmarked engine No. 1 may be given to any of the eight cylinders, and a correctly wired engine result, if the order of rotation is carried out.

This method is used by everyone familiar with firing orders, when at work upon a strange engine without a firing-order diagram as a guide, and, though the wiring may not be the same as when the engine left the factory, if the magneto has been removed, the result will be the same as though a wiring diagram had been used.

Where a distributor is marked at each segment designating what cylinder it is intended for, the marks may prove confusing if the magneto has been disturbed and not replaced correctly. The correctness of the magneto setting may quickly be checked if the distributor is marked and the cylinders marked or their method of numbering known, by placing a certain piston on *firing* top center, for instance, No. 1, and noting whether the distributor rotor then points to some other segment. If it is found that the rotor points to some other segment, it will become necessary to disregard all marks as explained, or reset the magneto.

With a clear understanding of four-cylinder engine firing orders and the knowledge that the power impulses alternate from one block to the other on an eight-cylinder V-type, there is little confusion in wiring an engine without numbers.

SIX- AND TWELVE-CYLINDER FIRING ORDERS

Before the theory of the twelve-cylinder firing order can be clearly understood, the firing orders of the six-cylinder must be mastered, for it bears the same relationship to the twelve-cylinder as the four-cylinder does to the eight-cylinder.

The twelve-cylinder V-type engine has the same crankshaft as the six-cylinder. Therefore, the firing order on one block, or bank of cylinders, of a twelve-cylinder engine will have a firing order which is a possible six-cylinder firing order.

In the four-cylinder engine with the cranks paired 1–4 and 2–3, there are but two possible firing orders, whereas in the six-cylinder there are eight possible firing orders. Four of these firing orders are obtainable from the so-called *right-hand* crankshaft and four from a *left-hand* crankshaft.

In Fig. 25*A*, is shown a *right-hand* crankshaft, and in Fig. 25*B*,

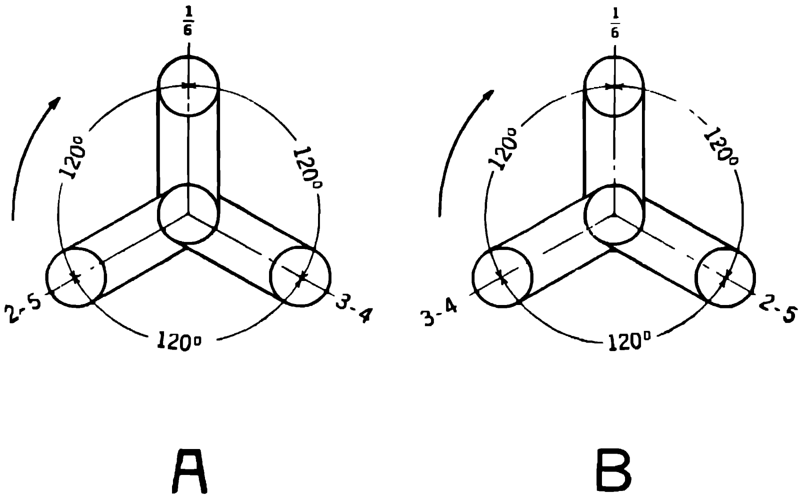


FIG 25

(*A*) Right-hand Crankshaft
(*B*) Left-hand Crankshaft

a *left-hand* crankshaft. With the pistons 1–6 on upper center in both cases, a *right-hand* shaft is distinguished from a *left-hand* crankshaft by the relation 3 and 4 cranks have to 1 and 6 cranks when viewed from the forward end of the shaft. If the center of the crankshaft, which is the crank throws 3 and 4, is on the observer's right, with 1 and 6 on upper center, the crankshaft is a *right-hand* shaft, as in Fig. 25. If the throws 3 and 4 are on the left, the shaft becomes a *left-hand* crankshaft.

Assuming that No. 1 cylinder has fired and the shaft turns to the right, pistons 2 and 5 will be next on upper center with the *right-hand* crankshaft. It is possible for either 2 or 5 to be on firing top center, depending upon the camshaft used. The same situation arises again

when further rotation brings the pistons 3 and 4 to upper center. The crankshaft will have completed one revolution when further rotating again brings 1 and 6 at upper center; therefore, three power impulses have occurred, and in the second revolution, the unfired cylinders work, completing the six power impulses.

With the proper camshaft to control the valves, it is possible to fire the first three cylinders in the order 1, 2, 3, followed by the last three firing 6, 5, 4. It would likewise be possible to reverse 3 and 4, causing the firing order to become 1, 2, 4, 6, 5, 3. The reversing of 2

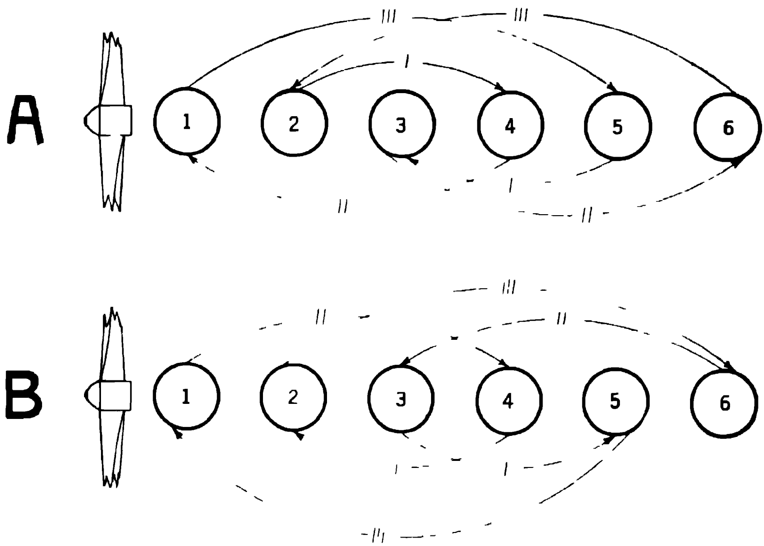


FIG. 26.

(*A*) Cylinders Jumped with Right-hand Crankshaft Firing Order.
(*B*) Cylinders Jumped with Left-hand Crankshaft Firing Order.

and 5 would then give the firing order 1, 5, 4, 6, 2, 3. Again the reversing of 3 and 4 would bring about the firing order 1, 5, 3, 6, 2, 4, which is the order commonly in use when a *right-hand* crankshaft is employed.

The same method may be used in finding the four possible firing orders obtainable from a *left-hand* crankshaft, though 1, 4, 2, 6, 3, 5 is the only one of the four which is used, and is the same to the *left-hand* crankshaft as 1, 5, 3, 6, 2, 4 is to the *right-hand* crankshaft.

In Fig. 26, a firing order of a *right-hand* crankshaft and a firing order of a *left-hand* crankshaft are laid out for comparison, and a check is

made of the number of cylinders skipped between power impulses; for instance, in the firing order 1, 5, 3, 6, 2, 4 there are three cylinders skipped between No. 1 firing and No. 5 firing, those jumped being 2, 3, and 4. Between No. 5 and No. 3 there is but one cylinder skipped, which is No. 4.

The last cylinder to fire is No. 4. Therefore, in returning to No. 1, which is the next to fire, there are two cylinders jumped, which are Nos 2 and 3. In passing through the firing order and returning to No. 1 again, there is a total of twelve cylinders jumped, in the order 111, 1, 11, 111, 1, 11, as shown in Fig. 26.

A close comparison of 1, 5, 3, 6, 2, 4 with the three remaining firing orders from a right-hand crankshaft discloses the unequal distribution of power impulses of the remaining firing orders, and accounts for the elimination of these orders in favor of 1, 5, 3, 6, 2, 4.

The same test applied to the *left-hand* crankshaft also proves the superiority of 1, 4, 2, 6, 3, 5, and likewise proves that it is not in any way unlike the order 1, 5, 3, 6, 2, 4.

It should be noted that in these two firing orders no adjacent cylinders fire in succession, which fact is of some importance in respect to the exhausting of gases. If, for instance, No. 1 cylinder fired and were followed by No. 2, the exhaust valve of No. 1 would still be open while No. 2 was exhausting; and with a single exhaust manifold, instead of individual stacks, the exhaust of No. 2 being at a greater pressure would interfere with the finishing exhaust of No. 1, which would be at a low pressure at the time. With the firing orders 1, 5, 3, 6, 2, 4 and 1, 4, 2, 6, 3, 5, this interference is reduced but is not eliminated entirely unless individual stacks are provided. Such restrictions, commonly known as *back-pressure*, may be further increased by a poorly designed exhaust pipe which has been carried back a considerable distance to act as a silencer.

The conditions just described and the considerations of vibration eliminates six out of the eight possible firing orders, leaving but two to memorize, the same as with the four-cylinder engine. With the two firing orders used in a six-cylinder engine mastered, the firing orders of a twelve-cylinder engine become less confusing. The twelve-cylinder engine is nothing more than two six-cylinder engines coupled to a single six-cylinder crankshaft.

It should be obvious that if the crankshaft of a six or twelve-cylinder could be seen, the firing order would be known without noting the valves in action. When the firing order is known on one block, or bank of cylinders, the firing order of the other block, or bank of cylinders, is likewise known, for if a *right-hand* crankshaft is employed, it governs

the firing order of both blocks, which fact makes the situation somewhat different from what is possible in the eight-cylinder engine.

In Figs. 27*A* and 27*B* is shown the usual method of numbering the cylinders. In Fig. 27*B*, the firing order of a *right-hand* is given. This arrangement is employed in the Liberty Engine, the Packard Models 3*A*-1500 and 3*A*-2500, and the Curtiss *D*-12.

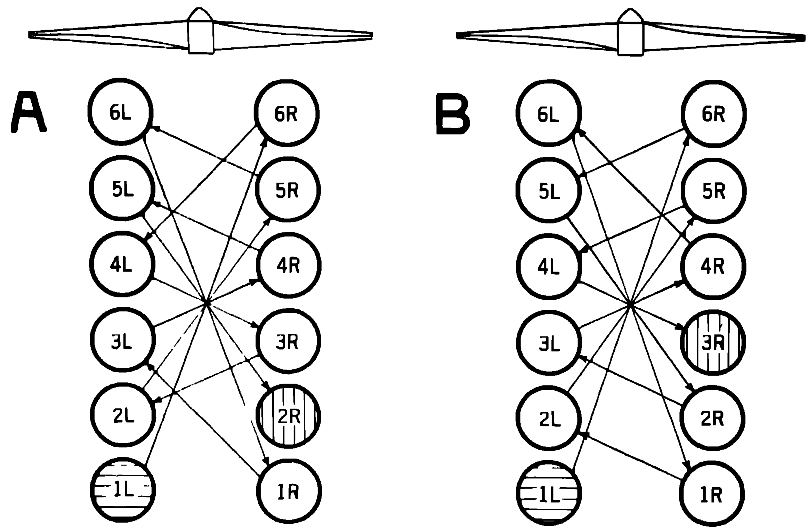


FIG. 27. Twelve-cylinder V-type Firing Orders.

(*A*) The firing order 1, 4, 2, 6, 3, 5, applied to both blocks resulting in the firing order 1L, 6R, 4L, 3R, 2L, 5R, 6L, 1R, 3L, 4R, 5L, 2R

(*B*) The firing order 1, 5, 3, 6, 2, 4, applied to both blocks resulting in the firing order 1L, 6R, 5L, 2R, 3L, 4R, 6L, 1R, 2L, 5R, 4L, 3R

ANGLE OF V-TYPE ENGINE CYLINDERS

In the timing and wiring of V-type engines, there is a likelihood of confusion arising with those engines which have the cylinder blocks set closer than the conventional 90 degrees on the eight-cylinder V-type, or 60 degrees on the twelve-cylinder V-type engine. In Fig. 28, the conventional construction is shown in which the blocks are 90 degrees apart. This arrangement is employed in the Curtiss OX-5 Engine. After a cylinder on the left bank fires, the crankshaft moves 90 degrees before a cylinder on the right bank fires, and a further movement of 90 degrees brings another cylinder on the left bank in firing position. In other words, every 90 degrees of crankshaft rotation brings a piston in firing position, the power impulses taking place at evenly spaced

intervals. This will be clear when it is realized that the cranks on the crankshaft are 180 degrees apart in an eight-cylinder V-type, just as

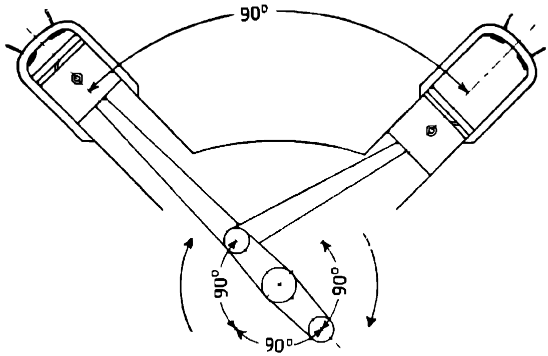


FIG. 28.—Eight-cylinder V-type Engine with Cylinder Blocks Set 90 Degrees Apart Resulting in Power Impulses Occurring Every 90 Degrees of Crankshaft Travel.

in a four-cylinder engine. This is simplified when it is clear that in two revolutions the crankshaft moves 720 degrees, as in all four-stroke cycle engines. In the case of an eight-cylinder engine, 720 degrees divided by 8 (cylinders) equals 90 degrees, which is the required distance the cylinders must be apart to provide evenly spaced power impulses.

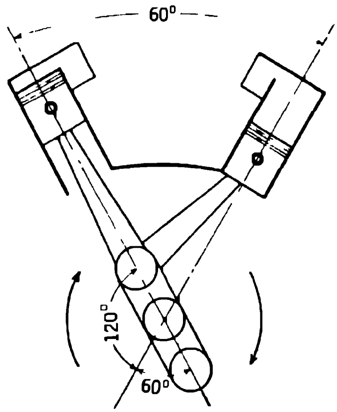


FIG. 29.—Eight-cylinder V-type Engine with Cylinder Blocks Set 60 Degrees Apart Resulting in Power Impulses Occurring at Intervals of 60, 120, 60, 120, etc.

The cylinder banks may also be set at other angles, for instance, 60 degrees, as in Fig. 29. This construction should lead to little confusion when the number of degrees between the power impulses is considered. After a cylinder of the left bank fires, a movement of the crankshaft 60 degrees will bring a piston of the right bank in firing position. It will be noted that to bring a piston of the left bank in firing position will necessitate rotating the crankshaft 120 degrees, followed by a movement of the crankshaft 60 degrees to fire again a cylinder of the right bank.

This alternate 60–120 of the power impulses makes up the 180

degrees of crank travel. In firing all eight cylinders there will be four occurrences of 60 degrees spacing, totaling 240 degrees; and four occurrences of 120 degrees, totaling 480 degrees. These degrees, when added, equal 720 degrees or the complete cycle.

The twelve-cylinder V-type engine of the conventional design has the cylinder banks set at an angle of 60 degrees, as in the Packard 3*A*-1500 and 3*A*-2500 engines, and the Curtiss *D*-12. The 60 degrees between the cylinder banks is one-half the number of degrees between the crank throws, for these engines have six-cylinder crankshafts in which the crank throws are 120 degrees apart. With the cylinder banks

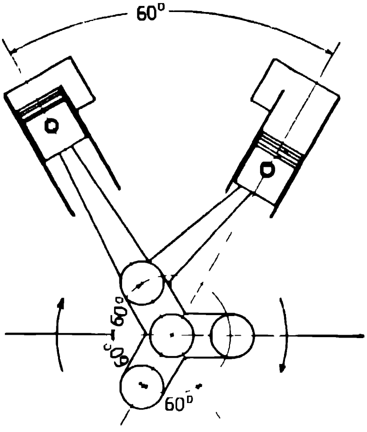


FIG. 30. Twelve-cylinder V-type Engine with Cylinder Blocks Set 60 Degrees Apart Resulting in Power Impulses Occurring Every 60 Degrees of Crankshaft Travel.

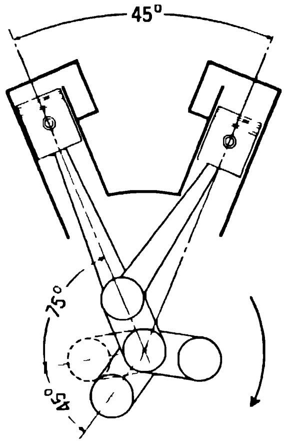


FIG. 31 Twelve-cylinder V-type Engine with Cylinder Blocks Set 45 Degrees Apart Resulting in Power Impulses Occurring at Intervals of 45, 75, 45, 75, etc.

set 60 degrees apart, the power impulses will be evenly spaced, as 12 × 60 equals 720 degrees or the complete cycle. The blocks may be set at other angles, for instance, 45 degrees apart, as in the Liberty Engine, as shown in Fig. 31. In this case, after a cylinder fires on the left bank, a cylinder on the right bank will fire after the crankshaft has rotated 45 degrees. The crankshaft will then be in a position which will require 75 degrees of crankshaft travel before a piston on the left bank is in firing position, giving the alternate firing spacing of 45, 75, 45, 75, etc.

In the complete cycle there will be six occurrences of 45 degrees spacing, totaling 270 degrees, and six occurrences of 75 degrees spacing,

totaling 450 degrees or 720 in all, in which time all the cylinders have fired.

The irregular firing on the eight- and twelve-cylinder engines described has some bearing upon the timing and wiring. The spacing upon the breaker cam operating the breaker contact points provides for the alternate, irregular firing, and if the breaker cam has been removed, it must be replaced so as to open the breaker contact points at the correct, irregular intervals.

On a twelve-cylinder V-type engine there are twelve lobes on the breaker cam. If the cylinders are set 45 degrees apart, there will be power impulses taking place 45 and 75 degrees apart. The cam having twelve lobes turning at one-half crankshaft speed will have the lobes arranged alternately 22½ and 37½, making it necessary to choose the correct lobe to provide for the irregular sequence of firing. This arrangement is encountered in the Liberty Engine, and accounts for the compulsory use of battery ignition on that engine for magnetos do not provide for irregular spacing.

The segments of the distributor for distributing the secondary current to the plugs of cylinders, arranged at 45 degrees on a twelve-cylinder V-type engine, are likewise arranged at alternate, irregular positions, corresponding to the opening of the breaker contact points, but will not add to the confusion once the correct lobe on the breaker cam is correctly set, for the distributor rotor, being keyed to the timer distributor shaft, will follow in order.

The setting of the cylinder banks of any V-type engine at an angle closer than that which will provide evenly spaced power impulses is for the purpose of diminishing head resistance and eliminating some vibration. Every engine has a natural period of vibration which can be detected by any loose object on an airplane when the engine is turning at some particular speed. In some engines the natural period of vibration occurs at lower engine speeds than it does in others. When the cylinders are set to provide evenly spaced power impulses, the natural period of vibration takes place within the limits of the engine's serviceable speed.

When the cylinder banks are set 45 degrees apart on a twelve-cylinder V-type engine, as in the Liberty Engine, the irregular power impulses prevent the appearance of the natural period of vibration within the serviceable speed range of the engine. An example of this can be cited in the marching of a troop of soldiers over a bridge. If the soldiers are in step, there is a possibility of their unison of step setting up waves of vibration of a period which might destroy the bridge. The order is always given to march rout step (out of step) while troops are crossing the bridge.

With the power impulses occurring at unevenly spaced intervals in an engine, it might be said that the cylinders are firing "out of step," for the comparison is identical.

EIGHT-IN-LINE FIRING ORDERS

When the firing orders of the four-cylinder engine are understood, the firing orders of engines having eight cylinders in line become simple. The crankshaft of an eight-cylinder-in-line engine is made up of two four-cylinder crankshafts, as shown in Fig. 32.

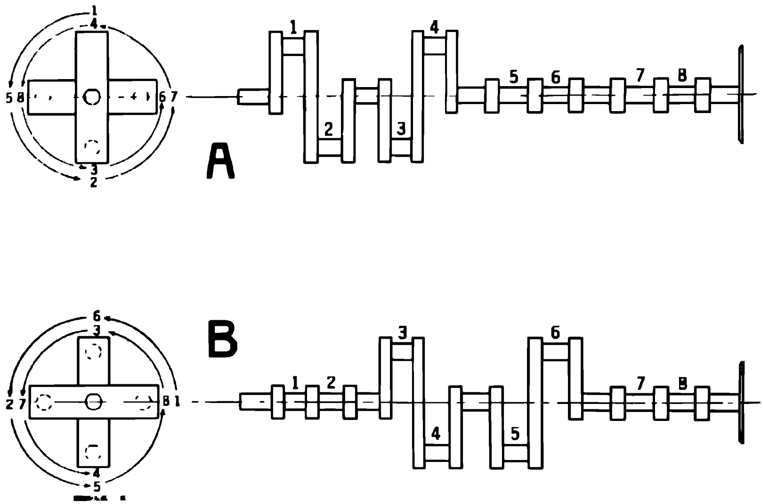


FIG. 32 Possible Crankshaft Arrangements for a Straight Eight.

(*A*) The 1-4 type straight eight crankshaft
(*B*) The 2-4-2 type straight eight crankshaft

In Fig. 32*A*, one four-cylinder crankshaft is arranged adjacent to another four-cylinder crankshaft with the crankpins of one shaft set 90 degrees to the crankpins of the other shaft. Starting with No. 1, the firing orders 1, 2, 4, 3 and 1, 3, 4, 2 may be carried out on each of the joined four-cylinder crankshafts.

In Fig. 32*B*, it is clearly shown that the crankshaft is made up of a four-cylinder crankshaft placed between the halves of another four-cylinder crankshaft, and set at a 90-degree angle. The firing order 1, 2, 4, 3 is carried out from the front to the rear of the split four-cylinder shaft, and from the rear to the front of center throws.

Fig. 32*A* represents the older design of eight-cylinder-in-line crank-

shaft, well known as the 4-4 type of shaft, which has given way in present-day practice to the 2, 4, 2 arrangement shown in Fig. 32*B*.

The foregoing discussion and diagrams have covered the field pertaining to firing orders of aircraft engines with a few exceptions, isolating which, it is believed, will clarify the confusion often resulting from comparison of automobile-engine firing orders with aircraft-engine firing orders.

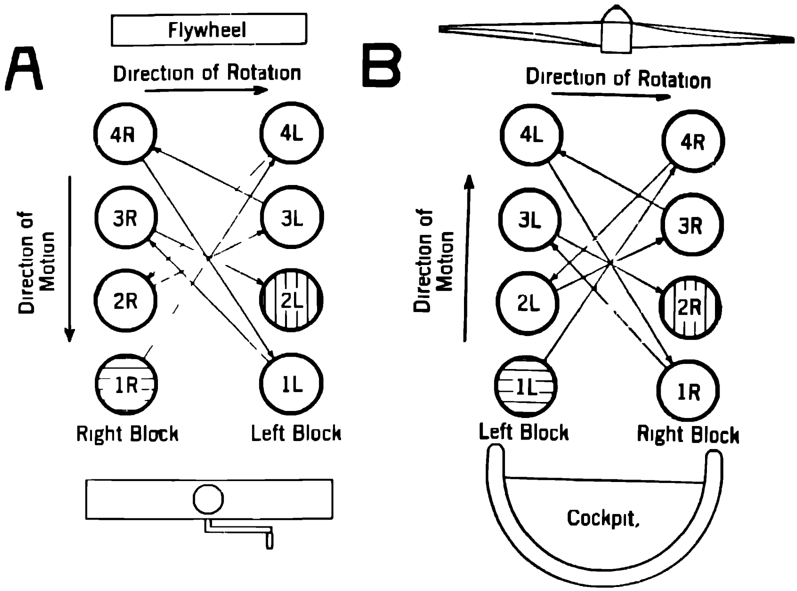


FIG 33 —Comparison of a Normal Automobile Engine and a Normal Aircraft Engine Relative to Firing Orders, Direction of Rotation and Direction of Motion.

(*A*) A normal eight-cylinder V-type automobile engine
(*B*) A normal eight-cylinder V-type aircraft engine

In Fig. 33, two engines having the same firing order are shown. One of these engines is a normal automobile engine turning to the right, and the other engine is a normal aircraft engine turning to the right. A little study of these engines will disclose that they are identical, with the exception that the right bank of one engine is designated as the left bank of the other engine. When it is realized that the automobile engine will be reversed when placed in the chassis, the right bank will then be seen to be on the driver's right when observed from the seat of the car, just as the right bank of the aircraft engine will be on the pilot's right when facing the engine from the cockpit of the conventional tractor-type airplane.

In Fig. 34, the firing order of a radial engine is given. This well-established arrangement of cylinders needs little explanation, for the jumping of a cylinder between working strokes brings a return to No. 1 after two revolutions when an odd number of cylinders are employed, which is compulsory with a single-throw crankshaft. Radial engines having a single-throw crankshaft must have an odd number of cylinders. If an engine has two throws to the crankshaft, there will be an odd number of cylinders to each throw. The double-throw crankshaft

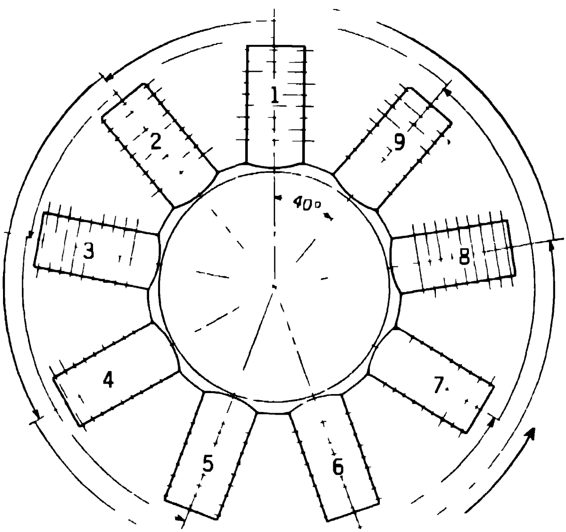


FIG. 34 – A Conventional Fixed Radial Type Engine Having Nine Cylinders Resulting in the Firing Order 1, 3, 5, 7, 9, 2, 4, 6, 8

results in an engine with an even number of cylinders, for two odd numbers invariably make an even number. See Fig. 35.

An odd number of cylinders is used on single-throw crankshaft radial engines for the following reason: On all four-stroke cycle engines two revolutions (720 degrees) are required to fire all the cylinders; therefore, on a radial engine having a single-throw crankshaft, in order to skip an unworked cylinder every firing stroke, the 720 degrees must be divided by an odd number to divide equally the power impulses. The odd number used determines the number of cylinders required.

There is another exception in firing orders which must be recognized, and that is the firing order of the unconventional cam-type drive engine.

The Fairchild-Caminez Aircraft Engine is a cam-type radial engine completing the four-stroke cycle in one revolution of the crankshaft, making it necessary to fire the cylinders consecutively, which gives the most simple firing order possible, namely: 1, 2, 3, 4.

FIG. 35. The Double-throw Crankshaft Six-cylinder Curtiss Challenger. Firing Order 1, 3, 2, 4, 6, 5.

SUMMARY OF POINTS ON FIRING ORDERS

Point 1.—Of the two possible firing orders for a four-cylinder engine there is no superiority of one over the other.

Point 2.—As a four-cylinder crankshaft is used in an eight-cylinder V-type engine, there are but two possible firing orders in a block or bank of cylinders, the same as in a four-cylinder engine.

Point 3.—It is possible for one block or bank of cylinders of an eight-cylinder V-type engine to have the firing order 1, 3, 4, 2, and the opposite block or bank to have the order 1, 2, 4, 3, though it is not the practice to use such construction.

Point 4.—A printed firing order for an eight-cylinder V-type engine

is useless unless designated by right and left bank method or the cylinders marked.

Point 5.—The right block or bank of cylinders of a V-type engine is on the right when the observer faces the engine from the anti-propeller end.

Point 6.—When No. 1 left ($1L$) is the first to fire in a V-type eight-cylinder engine, $4R$, in most cases, is the second to fire, regardless of what number it has, though it is possible for $1R$ to follow $1L$, as in the Curtiss OX-5 Engine.

Point 7.—The same principles that hold good for an eight-cylinder V-type engine may also be applied to a twelve-cylinder V-type engine.

Point 8.—A right-hand crankshaft differs from a left-hand crankshaft in respect to the relation the crank throws 3 and 4 have to the crank throws 1 and 6 when the latter are on upper center, and the term *right-hand* has nothing to do with the direction of rotation of the crankshaft.

Point 9.—A right-hand crankshaft turning clockwise gives the firing order 1, 5, 3, 6, 2, 4, and other possible orders; yet the same crankshaft rotating counter-clockwise would give 1, 4, 2, 6, 3, 5, or the firing order of a left-hand crankshaft when rotating clockwise.

Point 10.—In a four-cylinder and eight-cylinder V-type, the firing order is governed solely by the camshaft, while in a twelve-cylinder V-type engine, as well as in a six-cylinder-in-line engine, the camshaft and the crankshaft govern the firing order.

Point 11.—The firing order of an eight-cylinder-in-line engine depends upon the arrangement of the cranks upon the crankshaft.

CHAPTER IV

IGNITION TIMING

The method of controlling the spark variations on high-tension magneto ignition and battery ignition systems is fundamentally the same. With a movable timer-distributor housing on a battery ignition system and the movable breaker box on high-tension magnetos, advance is obtained by moving the housings against the rotation of the breaker cams, and retard is obtained by moving the housings in the direction of the cams rotation.

In Fig. 36, three positions of the piston are shown, representing 30 degrees advance in *A*, firing top center in *B*, and 10 degrees retard after firing top center in *C*, a total range of 40 degrees of spark timing variation.

If complete combustion can be brought about at firing top center as in *B*, the full benefit of the compressed charge is obtained and the maximum temperature reached, giving the greatest amount of force from expansion exerted against the piston. If the spark was timed to occur just as the piston reached top center position and combustion was instantaneous, the full benefit would be derived from combustion. The slowness of combustion prevents this, for in an engine in which the piston is moving rapidly and the spark is timed to take place at top center, the piston will have traveled some distance down in the stroke before complete combustion occurs. With the piston any degree down in the stroke the pressure is less, decreasing rapidly as the piston descends. Therefore, with complete combustion occurring any degree after top center, the expansion pressure will be less because of lowered temperature, resulting in a decrease in the force exerted against the piston head.

To compensate for the slowness of combustion a lead or advance must be given to the time the spark occurs. The greater the speed of the piston, the greater the lead necessary before top center to insure complete combustion by the time the piston has reached firing top center.

In *A* the advanced position of ignition is shown, and is the maximum

advance for some engines. At this point the spark starts the burning of the gas, first about the spark plug, and, as the temperature rises about the spark plug, the heat is rapidly radiated throughout the combustion chamber. If the speed of the piston is not great for this advance, all the compressed gas will be burning by the time the piston reaches top center, and the greatest efficiency will be reached by complete combustion taking place at top center.

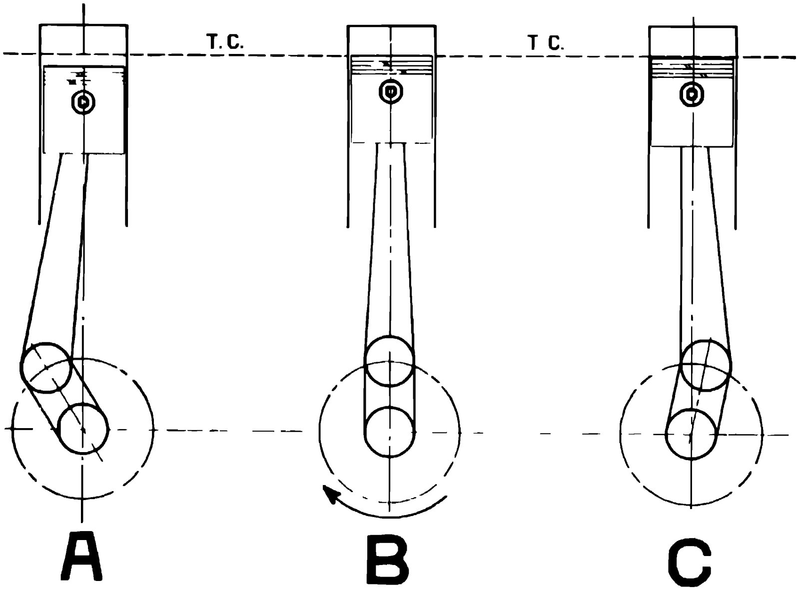


FIG. 36. Variation of Spark Timing.

(*A*) 30 degree advance.
(*B*) Retard at top center.
(*C*) 10-degree retard after top center.

Complete combustion occurring before top center gives lowered efficiency, as well as firing after top center. Should the spark be advanced too far for the speed of the piston, and complete combustion occur before the piston has reached the uppermost position, the force of expansion would tend to prevent the piston from continuing its progress upward, and severe knocking of the engine bearings and a loss of power would result. The stored-up energy in the revolving propeller prevents this early combustion from stopping the progress of the piston, unless the engine is "turning over" slowly, it then being possible to check the piston, resulting in the engine stalling.

If this early ignition and early combustion occur when starting the

engine, a *kick-back* results, for the revolving propeller imparts no energy sufficient to overcome the force against the piston. In *C* the ignition occurs well after top center. Therefore, complete combustion can exert force in no other way except in the right direction of rotation, for the piston has moved past top center, and the crank is over the dead center position.

Running an engine with the spark timed to occur in the retard position, as in *C*, when piston is moving rapidly, brings complete combustion far down in the stroke, resulting in a great loss of power from lowered pressure and also overheating, for the low pressure causes slow burning of the gas, and a greater area of the cylinder wall is exposed to the slow-burning fuel. Continued running on the retard position results in excessive fuel consumption, for to gain any power, greater opening of the throttle is necessary. Power is then obtained by full charges of slow-burning fuel, instead of from light charges of highly compressed fast-burning fuel.

There are many factors which determine the amount of spark advance necessary to insure maximum efficiency of the engine. Speed of the engine is the most important factor, for the higher the speed at which the engine rotates, the earlier the spark must occur, for the piston is traveling at greater speed. Compression, mixture, shape of combustion chamber, position of the spark plugs in the combustion chamber, and the penetrating power of the spark at the plugs—all bear directly upon the amount of advance necessary or permissible.

There can be no table to serve as an infallible guide in determining the limit the spark may be advanced. Only experimenting will determine the correct amount of lead for different engines; therefore, some unexpected variations are found in the timing of ignition systems.

A marked difference will be found in the timing of high-tension magnetos and battery systems, for magnetos automatically give an earlier spark as they reach high speeds, and a late spark as they are slowed down. This is caused by increase in the heat of the spark when the magneto armature is driven faster. A hot spark raises the temperature of the gas about the spark plug quicker than a cooler spark; therefore, combustion is more rapid with a spark of greater heat and penetrating power.

The speed of the magneto is not the only governing factor which increases the penetrating power of the spark on magnetos, for with the breaker in the advanced position on a shuttle type armature, as in the Berling and old-type Bosch magnetos, the primary current of the magneto is interrupted when the armature is in the position of maximum magnetic flux, whereas on retard the primary is being interrupted when

the armature has passed the point of maximum flux. Therefore, a weaker current is induced to flow in the secondary, and a weaker spark reaches the spark plugs. This inefficiency of the shuttle-type magneto on retard and the slow running of the magneto necessitate the advancing of the spark lever, to give a spark before firing top center, which insures easy starting.

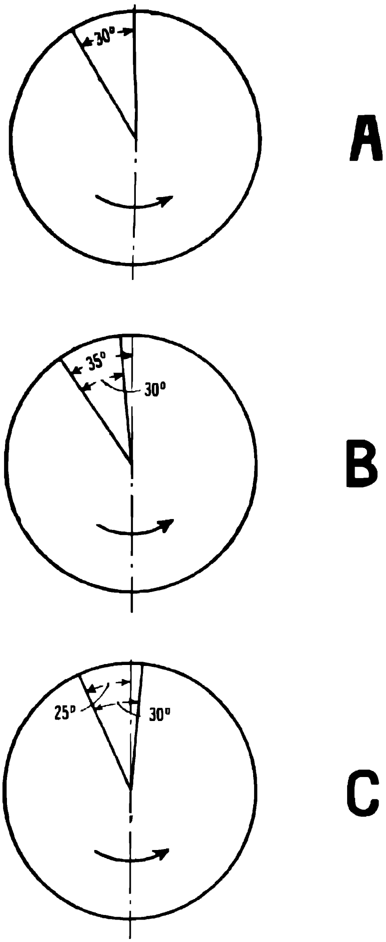


FIG. 37. Timing of a 30-degree Advance Magneto in Three Positions.

(*A*) Top center on retard
(*B*) 5 degrees before top center on retard
(*C*) 5 degrees past top center on retard

With an average advance of 30 degrees, a magneto may be set in several positions, as follows:

First.—The magneto may be timed on retard at top center; this position provides ample advance if the engine does not reach extremely high speeds. This position will also allow sufficient retard to relieve engine of early combustion on starting, for, in reality, complete combustion will take place later than top center, owing to the inefficiency of the magneto on retard and at low armature speeds. See Fig. 37*A*.

Second.—In the case of a very high-speed engine the magneto with a 30-degree advance range limit may require timing before firing top center on retard, in order to provide sufficient advance before firing top center. See Fig. 37*B*.

Third.—If the engine to be timed is a slow-speed engine, it may become necessary to time slightly after top center to prevent too great an advance being given to the pilot. See Fig. 37*C*.

These various settings depend upon the range of advance of the magneto and other factors governing spark advance, as more fully

explained under Timings of High-Tension Magnetos. In most cases the settings have been carefully worked out by experimenting at the factory, and the method of timing recommended by the manufacturer in his instruction book should be followed. The recommended timing may be measurements in inches or millimeters on the timing disc, or by fractions of an inch or millimeters of piston travel, and in any case may be on full advance or on full retard.

In the timing of battery ignition systems, the speed of the engine is no factor to be taken into consideration as far as the intensity of the spark is concerned, as it is with magneto ignition, for the source of current is practically of constant strength when taken from a battery and generator. At low engine speeds and at hand-starting speeds, the intensity of the spark being as great as at any time, ignition must be set somewhere after top center if the engine is to be started by hand. An example of such a timing is found in the Packard engines, the 3A-1500 engine being timed for an allowance of 25 degrees retard after top center, and the 3A-2500 engine being timed for an allowance of 10 degrees retard after top center.

In the case of starting by hand or by slow-turning starters, ignition must take place on retard late enough to prevent a *kick-back*, but when fast-turning starters are employed, slightly past firing top center is satisfactory. With a starter the engine is turned at a greater speed than the engine can be turned by hand. Consequently, the piston moves faster and will be slightly down in the stroke before the rich starting mixture of gas, which is slow burning, will reach a complete combustion degree.

In most cases the timing of battery ignition is recommended by the manufacturer to be set at *full-advance* position of the breaker, with a marked advanced position on the timing disc. When this method is used, the mechanical arrangement controlling the range of advance and retard provides the amount of retard allowed.

As there is no standard method of marking timing discs for ignition timing, a difference of engine designers' opinions is encountered, one advising timing on advance and another recommending timing on retard. The absence of timing discs upon engines while in service has resulted in some manufacturers furnishing ignition timing instructions by *piston travel*, instead of giving instructions for the use of a timing disc. In this event the directions for timing are given by furnishing the necessary information relative to the position of the piston in the cylinder.

It should be clearly understood that an engine timed on any full advance mark on a disc or by piston position will be correctly timed on

retard if the levers and rods *controlling the advance of the breaker have their correct movement. The reverse is likewise true.*

It should also be clearly understood that any mark on the timing disc is simply representing the position of the piston. Therefore, if the position of the piston is given in instructions, whether for advanced spark or retard spark, timing can be accomplished as accurately by *piston travel* as with a timing disc, though with not the same ease.

SETTING PISTON ON FIRING TOP CENTER

To time any ignition system, it is most essential to be familiar with the different methods a particular piston may be set on firing top center. It is customary to use No. 1 piston for timing, but it is not compulsory to do so. If No. 4 on a four-cylinder engine or No. 6 on a six-cylinder engine are more convenient for timing, they may be used, or any piston of the engine may be used.

If No. 1 piston is chosen for the timing, turn the propeller until No. 1 inlet valve opens and closes. The return of the valve to its seat indicates that the piston of that cylinder is moving upward on the compression stroke; when the piston reaches top center, firing top center has been reached.

With the timing disc in place bearing the top center marks, it is possible to determine when the piston is moving upward on compression by removing the spark plug and noting when air is being forced from the cylinder. When the air starts to be forced from the spark-plug opening, the timing-disc mark should receive all the attention and should be halted when a top center mark for 1 and 4 is reached, or whatever cylinder No. 1 is paired with.

Firing top center may likewise be found by watching the exhaust valve of the last cylinder, or, in other words, the exhaust valve of the cylinder with which No. 1 is paired. It should be clearly understood that if the last piston is moving up on the exhaust stroke, that valve will be closing; and, if the last piston is moving upward on the exhaust stroke, its mate, No. 1, must be moving upward on compression. It follows, then, that with the exhaust valve of the last cylinder about to close, the piston of that cylinder and its mate, No. 1, will be near top center; and the last piston being near top center at the end of the exhaust stroke, No. 1 piston will be near top center at the end of the compression stroke, or near **firing top center.**

The foregoing method of determining firing top center for No. 1 piston may, at first thought, be confusing, but when it is recalled that in every engine an exhaust valve closes near top center or from 10 to 15 degrees past top center, it will be clear that with any exhaust valve in

an engine about returned to its seat, the piston is near top center, and the mate to that piston will be near *firing top center.* For instance, on an engine where the exhaust valve is timed to close 5 degrees past top center and the engine is turned until the exhaust valve of the last cylinder just regains the clearance at the tappet, the piston will be slightly past top center, and No. 1 piston will be slightly past *firing top center.*

In finding firing top center by any of the methods explained it should be obvious that the same instructions hold good for one block of any V-type engine. If it is desired to set the piston of 1*R* on a twelve-cylinder engine, the last exhaust valve, which will be the exhaust valve of 6*R*, must be used, for it is the mate of No. 1*R*. It should also be understood that firing order never interferes with this method of finding firing top center, for regardless of what firing order is used, 1 and 4 are always paired in a four- or eight-cylinder V-type engine, and 1 and 6 are always paired in a six- or twelve-cylinder V-type engine.

PREPARATIONS FOR TIMING

In the timing of ignition systems, it is also necessary to have a correct understanding of the mechanical movement of all mechanism controlling spark advance and retard. Some controls have the retard and advance positions marked. Regardless of marks, the workman should be able to distinguish, by an understanding of the principles involved, when the breaker contact points are opening late or early.

When it is intended to time the ignition on retard spark, the breaker mechanism must be placed in the *full-retard* position. If it is intended to time the ignition on advance spark, the breaker mechanism must be placed in the *full-advance* position. To obtain the accurate position on either retard or advance, the rods and levers controlling the operation should be correctly connected with the control in reach of the pilot.

Before proceeding to time the ignition, it likewise is necessary to adjust, by the use of a thickness gage, the breaker contact points to the recommended distance when the cam is holding the breaker contacts apart the maximum amount permitted by the lobes of the breaker cam. In the absence of any information regarding the space between the breaker contacts, an average distance of from 0.015 to 0.020 in. should be allowed on battery ignition systems, and an average of 0.015 of an inch on magnetos, though guesswork cannot be too strongly condemned.

In the timing of a V-type engine having battery ignition and the cylinders set closer than the angle which would provide evenly spaced explosions, it is of vital importance to use the correct lobe of the breaker cam, as explained under Firing Orders.

TIMING BATTERY IGNITION ON RETARD BY DISC MARK

The following method should be employed when timing battery ignition on retard by a timing disc mark:

First.—Find the firing order of the engine.

Second.—Adjust the breaker contact points by the use of the correct thickness gage recommended by the manufacturer.

Third.—Set No. 1 piston on *firing top center*. Note the timing disc, and if it bears a retard ignition mark which is past firing top center, turn the crankshaft until mark is under the pointer which must correspond with an imaginary center line through the engine cylinder, unless a more accessible point is indicated.

Fourth.—With the spark lever in the *full retard* position, the breaker cam must be set so that the slightest movement of the spark lever toward the advance position will cause the breaker contact points to start opening. That lobe of the breaker cam must be used which will cause the rotor of the distributor to be in contact with the segment of the distributor connected with No. 1 spark plug.

Fifth.—The engine should next be turned two revolutions or backed up a quarter of a revolution, so that the firing top center for No. 1 may be again brought up to permit noting whether lost motion in the timer-distributor drive interfered with the timing at firing top center.

Sixth.—Connect the remaining wires to the spark plugs according to the firing order, exercising caution to connect the wires according to the direction of rotation of the distributor rotor.

TIMING BATTERY IGNITION ON ADVANCE BY DISC MARK

To insure the ignition being timed with a maximum amount of advance, most engine designers place a mark on the timing disc indicating the position where the breaker contacts are to open with the spark lever in the *full-advance* position.

The same procedure should be followed as explained in the preceding instructions for timing battery ignition on retard, with the exception of setting the spark lever in the *full-advance* position and placing the timing disc mark for advanced timing under the pointer, which will be at some position *before firing top center*.

TIMING HIGH-TENSION MAGNETO ON RETARD BY DISC MARK

To time a high-tension magneto on retard by a timing disc mark, the following instructions should be employed:

First.—Find the firing order of the engine.

Second.—Adjust the breaker contact points to the recommended

clearance, Scintilla, 0.012 in.; Berling, 0.018 to 0.020 in. If the correct clearance for a particular make of magneto is not known, every effort should be made to obtain the correct spacing. To have the correct information as to the space between the breaker contacts is of greater importance on magnetos than on battery systems.

Third.—Set No. 1 piston on *firing top center.* Note the timing disc, and if it bears a retard ignition mark which is *before* or *after* firing top center, turn the crankshaft until mark is under the pointer which must correspond with an imaginary center line through the engine cylinder, unless a more accessible point is indicated.

Fourth.—With the breaker box of the magneto in the *full-retard* position, the magneto coupling must be connected or gear-driving magneto meshed, so that the slightest movement of the spark lever toward the advanced position will cause the breaker contact points to start opening. The magneto armature must also be placed in the position that will cause the distributor brush to be in contact with the segment of the distributor connected with No. 1 spark plug.

Fifth.—The engine should next be turned two revolutions or backed up a quarter of a revolution, so that the firing top center for No. 1 can be again brought up to permit noting whether lost motion in the magneto drive interfered with the timing at firing top center.

Sixth.—Connect the remaining wires to the spark plugs according to the firing order, exercising caution to connect the wires according to the direction of rotation of the distributor brush.

TIMING MAGNETO ON ADVANCE BY TIMING DISC MARK

To time a magneto on advance by timing disc mark follow the same procedure as given under Timing High-Tension Magneto on Retard Disc Mark, with the exception of setting the spark lever in the *full-advance* position, and the timing disc on the advance mark.

TIMING THE MAGNETO WITHOUT MARKS OR OTHER INSTRUCTIONS

To time a magneto without marks or other timing instructions the following method is suggested:

First.—Find the firing order of the engine.

Second.—Adjust the breaker contact points an average of 0.015 in. on shuttle-type magnetos unless the correct spacing is known; every effort should be made to obtain the correct spacing. Some inductor type magnetos require a space of 0.020 in. while others require but 0.012 in. To have the correct information as to the space between the breaker contacts is of great importance on some types of magnetos.

Third.—Set No. 1 piston on *firing top center.*

Fourth.—With the breaker box of the magneto in the *full-retard* position, the magneto coupling must be connected or gear-driving magneto meshed, so that the slightest movement of the spark lever toward the advanced position will cause the breaker contact points to start opening. The magneto armature must also be placed in the position that will cause the distributor brush to be in contact with the segment of the distributor connected with No. 1 spark plug.

Fifth.—The engine should next be turned two revolutions or backed up a quarter of a revolution, so that the firing top center for No. 1 can be again brought up to permit noting whether lost motion in the magneto drive interfered with the timing at firing top center.

Sixth.—Connect the remaining wires to the spark plugs according to the firing order, exercising caution to connect the wires according to the direction of rotation of the distributor brush.

It has previously been explained that greater variations are found in the timing of magnetos on retard than are found in the timing of battery ignition on retard. In the instructions just given for timing the magneto without any timing instructions, *firing top center* has been recommended; but it is of the utmost importance that this should not be taken as an unbreakable rule, for there are several points in respect to magnetos which may make it necessary to time at another position beside firing top center.

After the magneto has been timed on retard at top center, a test will quickly determine whether the magneto has been given sufficient advance before top center by the timing at top center on retard. If the engine does not turn up its maximum speed, or there are any indications of overheating, an earlier timing than top center on retard should be tried. The range of the spark advance may make it necessary to time the magneto 5 degrees before top center on retard in order to obtain sufficient advance. In this event a kick-back must not be expected, for, as previously explained, a magneto on retard spark and turning at starting speed does not furnish a very hot spark, which in itself is automatically later than a hot spark. The armature of a shuttle-type magneto is also in an unfavorable position in the magnetic field when the spark is retarded, which has the effect of further decreasing the intensity of the spark.

On the other hand, the magneto may be timed as instructed at firing top center on retard, and a test may prove that the magneto is receiving more advance than is advisable for inexperienced pilots. In this event the magneto may be timed 5 to 10 degrees past firing top center on

retard, to prevent too great a lead of the spark when the lever is in the advance position.

In Fig. 37 a self-explanatory drawing is shown of three timings for a magneto of a type that has a sparking range of 30 degrees, applied to three engines requiring different timings. It is obvious that it is not always practicable to design a magneto for the individual requirements of every engine made, when a slight variation in the timing of the magneto on retard will bring about satisfactory results.

The sparking range of battery systems is greater than that of magnetos, and accurate timing is readily obtainable, and likewise is necessary, but with magnetos the factors governing the amount of advance makes the systems call for different treatment.

Magnetos are built with a sparking range which depends to a certain degree upon their speed, and one type of magneto may be adapted to several engines. As shown in Fig. 37, a magneto timed at firing top center may be correct for one engine, and yet the same magneto on another engine may require the magneto timed 5 degrees before top center to obtain the necessary advance, or after top center in another instance to prevent too great an advance.

TIMING HIGH-TENSION MAGNETO BY PISTON TRAVEL

The timing of magneto by piston travel on retard is explained in the preceding instructions for Timing High-Tension Magneto without Marks or Other Timing Instructions.

The timing of a magneto by piston travel on advance is accomplished by setting the piston in the recommended position *before firing top center,* and following the instructions given for Timing High-Tension Magneto on Retard by Timing Disc Mark, with the exception that the magneto breaker box must be placed in the advanced position and the piston set in the recommended position before firing top center. Because of the variations of magneto sparking range, many engine makers furnish the advanced timing for the magneto in their instruction book to insure correct timing on advance, and any variation from top center on retard, that results from the timing on advance, is of little interest. as previously explained.

TIMING HIGH-TENSION MAGNETO BY PISTON TRAVEL WITHOUT INSTRUCTIONS

To time a high-tension magneto by piston travel without instructions, follow the same instructions as for Timing High Tension Magneto without Marks or Other Timing Instructions.

TIMING "SET SPARK" MAGNETO

It has been explained that a magneto is self-advancing to some extent, because of its furnishing a hotter spark as the speed of the armature is increased. When the magneto armature is being driven at a low speed, the output of current is low, and the penetrating power of the spark is reduced, causing combustion to be slower, which amounts to the same thing as being later. As the speed of the armature increases, the intensity of the spark increases, causing combustion to be more rapid and amounting to the same thing as an earlier spark.

The variation of the self-advancing and self-retarding peculiarity in a magneto is not great, yet sufficient to permit a magneto being used without any mechanical means of advancing and retarding the spark. The advance and retard control of the magneto is wired or in some other way secured in the full-advance position of the breaker, and the magneto timed to the engine on full advance. This arrangement is encountered in the Curtiss OX-5 Engine, the Berling magneto being timed from 28 to 32 degrees before firing top center, and the breaker secured in the full-advance position.

On other engines equipped with Scintilla magnetos it is possible to set the magneto full advance and secure the breaker in the full-advance position, providing the propeller is swung by hand. If the same engines are equipped with a hand starter or an electric starter, it is necessary for the magneto to be equipped with a spark advance and retard control, so that the spark can be retarded when starting with the starter. This arrangement is necessary because of the increased speed of the magneto when a starter is used. The magneto output is increased when the starter revolves the engine rapidly, and the increased output of the magneto creates too early a spark for a full-advance setting when starting the engine.

On the "set spark" magneto, there being no means to change the time the breaker contact points open and close, they open at the same position of the piston at all engine speeds. In order to obtain sufficient advance at high speeds, the contact points open about 25 degrees before top center on the average Scintilla equipped engine. The amount of lead or advance is best found by experimenting, unless the manufacturer has furnished instructions to time by piston travel or provided a marked timing disc for the position at which the breaker points are to open.

If a timing of the breaker contact points to open 25 degrees before top center plus the increased advance provided by the hotter spark at high magneto speeds is sufficient to give maximum efficiency at high engine speeds, the magneto would be timed accordingly. The lead

might be as much as 30 degrees before top center, depending upon the speed of the engine and the output of the magneto.

It will be obvious that the breaker contact points opening 25 degrees before firing top center will make it impossible to obtain any later ignition at low engine speeds than 25 degrees before top center, except from that which is obtained from the reduced output of the magneto at low speed.

TIMING AND SYNCHRONIZING THE MAGNETOS ON THE PRATT & WHITNEY HORNET ENGINE

The magnetos on the Hornet Engine should be set to break 30 degrees before firing top center when fully advanced.

To time the magnetos, turn the crankshaft counter-clockwise so that the No. 1 piston is on the compression stroke (both valves closed) and the timing pointer registers with the 30-degree advance mark on the front of the crankcase. Take off the magneto breaker covers and also the outside distributor blocks (the right-hand block of the right magneto and the left-hand one of the left magneto). Remove the lock wires from the magneto couplings and slip the couplings back (toward the magnetos) until they are disengaged. If the spark control rod is connected, place the control in the fully advanced position.

Set each magneto to break for No. 1 cylinder.

There are marks on the frame of the magneto alongside the distributor block, and on the brass gear inside. On the right side of magneto two marks on the gear register with two marks on the frame, and on the left of the magneto one mark on each part. Turn the gear with the fingers until the marks register. Hold the gear and turn the magneto coupling around until it goes into place. The breaker points should be closed but *just ready to open.*

Place a strip of cigaret paper between the breaker points of each magneto and adjust each magneto coupling so that the paper will just pull. To do this, hold the brass gear inside the magneto with the fingers, disengage the couplings and turn it one tooth backward (clockwise as viewed from the rear) and engage it again. Repeat this with each magneto until the cigaret paper just becomes loose between the contacts.

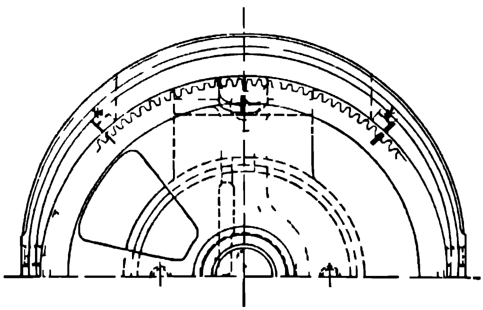
Check the timing by turning the crankshaft clockwise half a turn and coming slowly up to the firing point, holding the cigaret papers and noting the exact point at which each one becomes loose. The two magnetos must break at the same moment. After the setting is correct, put the snap rings on the magneto couplings. Put on the distributor blocks and the breaker covers, and secure with safety pins.

Remove the timing pointer from the crankshaft, and put on the

front bearing cover plate with the drain at the bottom. Screw up the cover plate nuts and wire them in place.

Fasten the spark-plug cables to the distributor blocks. The numbers on the distributor blocks show the serial firing order of the magneto

Both magnetos must be set to break together



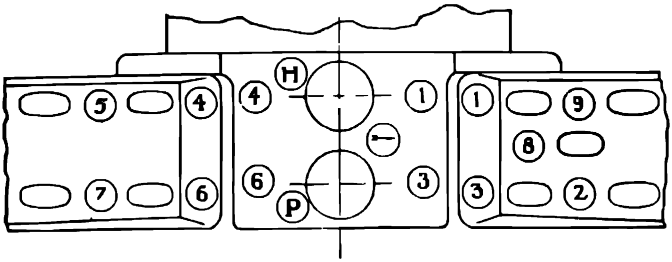
Timing marks on magneto

Fig. 38. Timing Magneto

The numbers on the top of the main cover are for the purpose of locating the right and left distributor blocks to their respective sides.

Observe that each magneto is wired to its proper set of wires as given in specifications, and that the wires lead from the magneto so that No. 1 on the distributor blocks goes to No. 1 or first cylinder in the

firing order of the engine, while No. 2 on the distributor block goes to the second cylinder in the firing order of the engine, which is No. 3. No. 3 on the distributor block goes to the third cylinder in the firing



Drive Shaft End.

Connection diagram of the AG 9–D clockwise rotation.

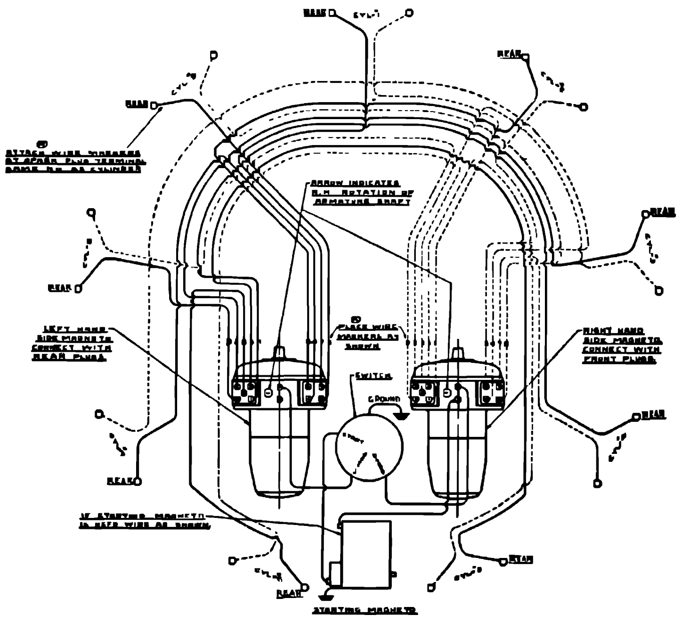


FIG. 39. Wiring Diagram.

Firing order 1, 3, 5, 7, 9, 2, 4, 6, 8. View looking at magneto end of engine.

order of the engine, which is No. 5, etc., until all cylinders have been wired in their proper firing order. Clamp distributor blocks in place. The firing order is 1, 3, 5, 7, 9, 2, 4, 6, 8.

The letter *H* marks the terminal to which the booster wire is to be connected.

The letter *P* marks the terminal to which the ground or short-circuiting wire from the magneto switch is to be connected.

The arrow indicates direction of rotation of the magneto when viewed from the drive end.

Tighten and lock the drive coupling. The advance lever linkage is to be connected to the advance lever on the magneto, special attention being given that full advance and retard are obtained when the spark lever in the cockpit is moved to its full advance and retard positions.

SYNCHRONIZATION OF DOUBLE IGNITION SYSTEMS

Double ignition systems have become an accepted necessity upon all engines, and as the name implies, the system consists of two distinct and separate ignition systems. Double ignition, also called dual ignition, may be comprised of two high-tension magnetos each firing all the cylinders of the engine, or two separate battery ignition units, each firing all the cylinders of the engine, as on the Packard and Liberty engines.

In the timing of the ignition on an engine equipped with double ignition, it is not only necessary to time each system in relation to the position of the piston, but it is highly advantageous, in some cases, so to time the two systems that they are synchronized, that is, agree in time, as fully explained under Timing and Synchronizing the Magnetos on the Pratt & Whitney Hornet Engine.

It should not be understood that all engines equipped with double ignition are synchronized, for in some engines a definite timing is required for the ignition system which fires the spark plugs nearest the inlet valves, and a different timing for the ignition system which fires the spark plugs nearest the exhaust valves. The recommended timing may require several degrees' earlier timing for the exhaust side. An example of such a timing is found in the Curtiss D-12 Engine, the exhaust magneto being set 36 degrees before top center on full advance, and the inlet magneto being set but 32 degrees before top center on full advance on the *low compression* D-12 Engine. On the *high compression* Curtiss D-12 Engine, the exhaust magneto is set 38 degrees before top center on full advance, and the inlet magneto is set 33 degrees before top center on full advance.

On the Kinner K-5 Engine the left magneto is timed 26 degrees before top center, and the right magneto is timed 25 degrees before top center.

On some battery ignition systems the distributor may be found to have two sets of breaker points connected in parallel, and to insure

both sets of points doing their share of carrying and interrupting the current, they must be synchronized. When these double breaker points have been synchronized on each unit of a double ignition system, the two units may be synchronized at the recommended timing. A check of retard ignition timing may disclose a variation from synchronization, but this should be ignored in favor of correct timing on the advanced spark, for it is upon the advanced spark that it is highly desirable to have the two systems in step. The foregoing description of dual breaker contact points and their synchronization applies to the battery ignition system of the Liberty Engine.

SUMMARY OF POINTS ON IGNITION TIMING

Point 1.—It is customary in all instructions given for timing ignition to designate No. 1 cylinder for the timing, though the ignition may be timed upon any cylinder if firing top center or other indicating mark is used, and the distributor brush is correctly set for that cylinder.

Point 2.—It is of the greatest importance to be certain the piston used for timing is on *firing* top center, and not on top center at the end of the exhaust stroke.

Point 3.—It is advantageous to have the correct information regarding the space between the breaker contact points, particularly with some type of magnetos.

Point 4.—Most engines equipped with fast-turning starters and battery ignition are timed on firing top center, and preferably after top center.

Point 5.—No ignition system must be mistimed on retard so as to sacrifice the lead of the spark on full advance, or inefficiency will be the result and lowered revolutions per minute. It is for this possible error that some engine designers furnish advance timing marks to insure maximum advance, in case rods and levers controlling advance have been altered.

Point 6.—Marks on a timing disc are nothing more than a convenient way to determine the position of the pistons. It should be remembered that it is not the timing disc which is of interest but what the marks on the timing disc represent, which is the position of the piston.

Point 7.—A magneto found timed on retard before firing top center or after top center does not indicate that the magneto is out of time, if it is timed correctly on the advanced position.

Point 8.—In reading instructions for timing the ignition by piston travel, be certain whether the measurement set down by the manu-

facturer is for measuring the piston position before firing top center, or is a measurement to be taken from the top of the cylinder barrel. In any instructions for timing by timing disc it is of the greatest importance to note whether the instructions read in degrees, inches, or millimeters. Remember that an inch is always an inch, and a millimeter always a millimeter, but a degree on a large timing disc is greater than a degree on a small timing disc, as a degree is always $\frac{1}{360}$ part of the circumference of the disc.

Point 9.—Though the principle remains the same in all ignition timing, there are no set rules except that the ignition must be early enough for efficiency on full advance, and late enough on retard to prevent a kick-back.

Point 10.—Without timing information, it becomes necessary to experiment with the timing of a set spark magneto before the most efficient timing for all conditions can be determined; and it is impossible for anyone to know the timing without previous experience with the particular type of magneto and engine in question.

TABLE OF IGNITION TIMINGS

PRATT & WHITNEY HORNET A-1:
30 degrees before top center on both magnetos (full advance).

PRATT & WHITNEY WASP (all models):
30 degrees before top center on both magnetos (full advance).

WRIGHT WHIRLWIND J-4A, J-4B, J-5:
30 degrees before top center on both magnetos (full advance).

WRIGHT WHIRLWIND J-6 SERIES, NINE, SEVEN, AND FIVE CYLINDERS:
25 degrees before top center on both magnetos (full advance).

KINNER K 5:
Left magneto 26 degrees before top center. Right magneto 25 degrees before top center (full advance).

AMERICAN CIRRUS:
Inlet side 35 degrees before top center. Exhaust side 40 degrees before top center (full advance).

WARNER SCARAB:
32 degrees before top center on both magnetos (full advance).

CURTISS D-12 LOW-COMPRESSION ENGINE:
Inlet magneto 32 degrees before top center. Exhaust magneto 36 degrees before top center (full advance).

CURTISS D-12 HIGH-COMPRESSION ENGINE:
Inlet magneto 33 degrees before top center. Exhaust magneto 38 degrees before top center (full advance).

PACKARD 3A-1500 LOW-COMPRESSION ENGINE (MAGNETO EQUIPPED):
40 degrees before top center on both magnetos (full advance).

PACKARD 3A-1500 HIGH-COMPRESSION ENGINE (MAGNETO EQUIPPED):
35 degrees before top center on both magnetos (full advance).

PACKARD 3A-1500 LOW-COMPRESSION ENGINE (BATTERY IGNITION):
40 degrees before top center on both distributors (full advance).

PACKARD 3A-1500 HIGH-COMPRESSION ENGINE (BATTERY IGNITION):
35 degrees before top center on both distributors (full advance).

CURTISS CHALLENGER:
35 degrees before top center on both magnetos (full advance).

PACKARD 3A-2500 LOW-COMPRESSION ENGINE (MAGNETO EQUIPPED):
50 degrees before top center on both magnetos (full advance).

PACKARD 3A-2500 HIGH-COMPRESSION ENGINE (MAGNETO EQUIPPED):
44 degrees before top center on both magnetos (full advance).

PACKARD 3A-2500 LOW-COMPRESSION ENGINE (BATTERY IGNITION):
50 degrees before top center on both distributors (full advance).

PACKARD 3A-2500 HIGH-COMPRESSION ENGINE (BATTERY IGNITION):
44 degrees before top center on both distributors (full advance).

CURTISS OX-5:
28 to 32 degrees before top center (single magneto) (full advance).

LIBERTY 12:
30 degrees before top center on both distributors (full advance).

LEBLOND SIXTY AND NINETY:
25 degrees before top center on both magnetos (full advance).

AXELSON A:
40 degrees before top center on both magnetos (full advance).

HISPANO-SUIZA:
32 degrees before top center on both magnetos (full advance).

VELIE M-5:
30 degrees before top center on both magnetos (full advance).

CHAPTER V

AIRCRAFT MAGNETOS *

At the present stage of the aircraft industry inductor-type magnetos are the standard equipment on the majority of new production aircraft engines, and the inductor type magneto as built by the Scintilla Company, being most frequently encountered in the field, will serve as a typical example of modern magneto practice.

The Scintilla Magneto is an inductor-type magneto employing a rotating magnet. The rotating magnet is made of special chrome magnet steel, and has either two or four poles, depending upon the type of magneto in which it is used.

The extremities of the poles of the rotating magnet are laminated, the laminations being held in place by an end plate on which the breaker cam is mounted. The rotation of the magnet produces reversals of magnetic flux through the core of a coil which is mounted directly on the extensions of the laminated pole shoes.

The Coil, which consists of the primary and secondary winding, between which is placed the condenser, is stationary and well protected from oil and grease.

The Breaker.—The contact-breaker mechanism is of the rocker lever type actuated by either a two- or four-lobe cam. The cage on which the various parts are assembled to form the complete breaker mechanism can be readily removed from the magneto without the use of any tools whatever.

Circuit Connections.—All primary connections within the magneto are made by means of laminated leaf springs, thus insuring positive and reliable connections. All Scintilla magneto types designated with letters and numbers ending with a *D* have provision made for booster starting. This connection permits the introduction of high-tension current from an external source, thus facilitating the starting of the engine.

The Distributor Blocks are mounted so that they are held between the main cover and the front end plate. Their lower ends rest upon the

* The data in this section are presented through the courtesy of The Scintilla Magneto Co.

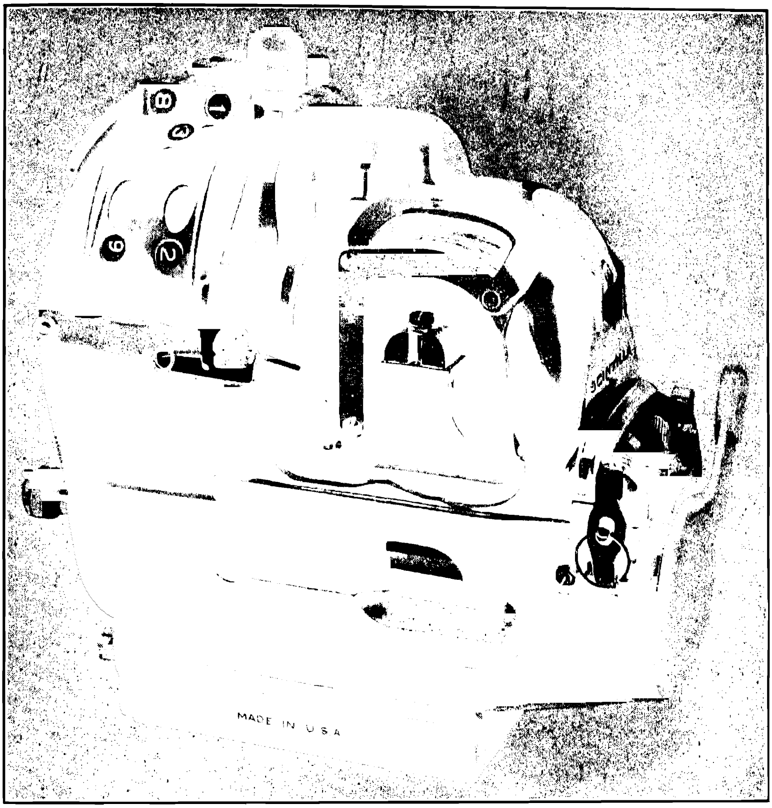


FIG. 40.—The Scintilla Aircraft Magneto.

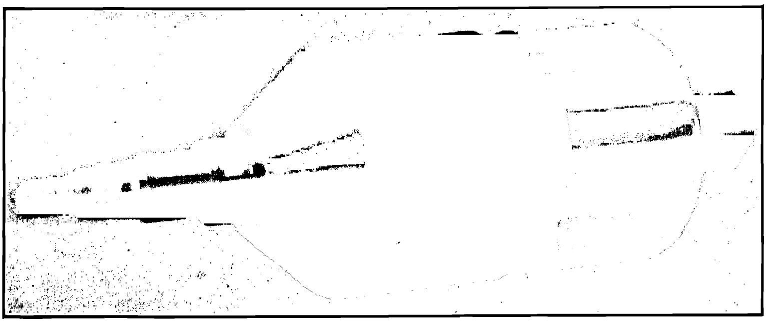


FIG. 41.—The Rotating Magnet.

magneto housing and the upper ends fit against the top extension of the main cover. They are held in place by spring clamps and are designated

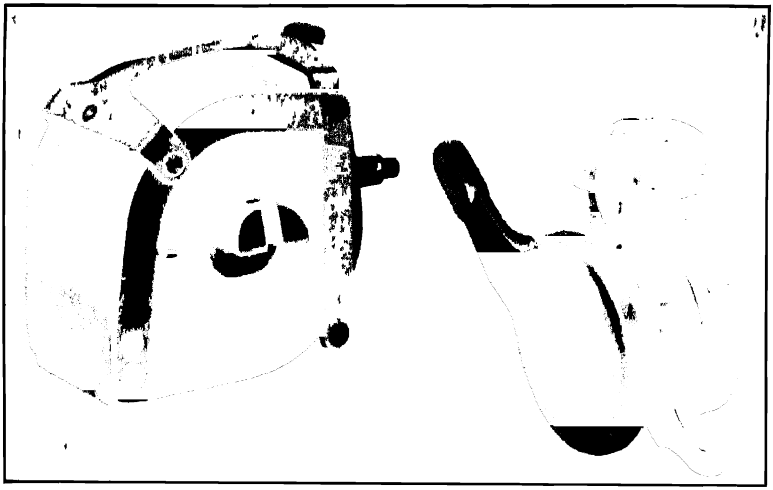


FIG. 42.—The Stationary Primary and Secondary Winding, and the Breaker Assembly.

as the Right and Left distributor block as viewed from the drive end.

The Magneto Housing encloses the rotating magnet. It carries the outer race for the breaker end bearing, the ground plate for safety gap, the breaker cover spring clamps, and the dowel pins for locating the main cover and breaker cover. The pole shoes are laminated and cast as an integral part of the magneto housing. The breaker stop and fastening screw are located in the lower part of the breaker end of the magneto housing.

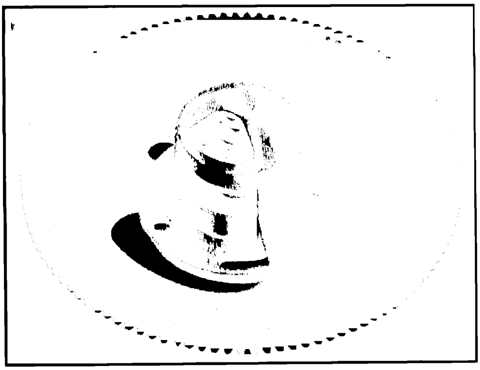


FIG 43.—The Distributor Gear.

The Main Cover with Booster and Ground Connection Block.—The main cover is located by four dowel pins and is fastened to the magneto

housing by two screws. It affords protection to the coil from moisture, oil, and dirt under abnormally severe operating conditions. The booster and ground connection block is mounted in the extension of the main cover between the distributor blocks. It is secured by two screws. The booster and ground connection block carries the ground terminal and the stud for ground contact, also the booster terminal and the electrode for the booster current. The stud for ground contact bears on a spring plate secured to the primary bridge. The electrode for the booster current is held directly over the collector ring for the booster current. There is a small air gap between the electrode and the collector ring.

At the top of the main cover are provided numbers for locating the distributor blocks, an arrow showing the direction of rotation of the magneto and the two letters *H* and *P* to mark the Booster and Ground terminals, respectively.

ELECTRICAL OPERATION OF MAGNETO

Magnetic Field and Contact Breaker.—The rotating magnet (1) has four poles. The poles are joined together inside the laminated ends into pairs. The two *N* poles making up one pair and the other two *S* poles making up the other pair. See Fig. 44.

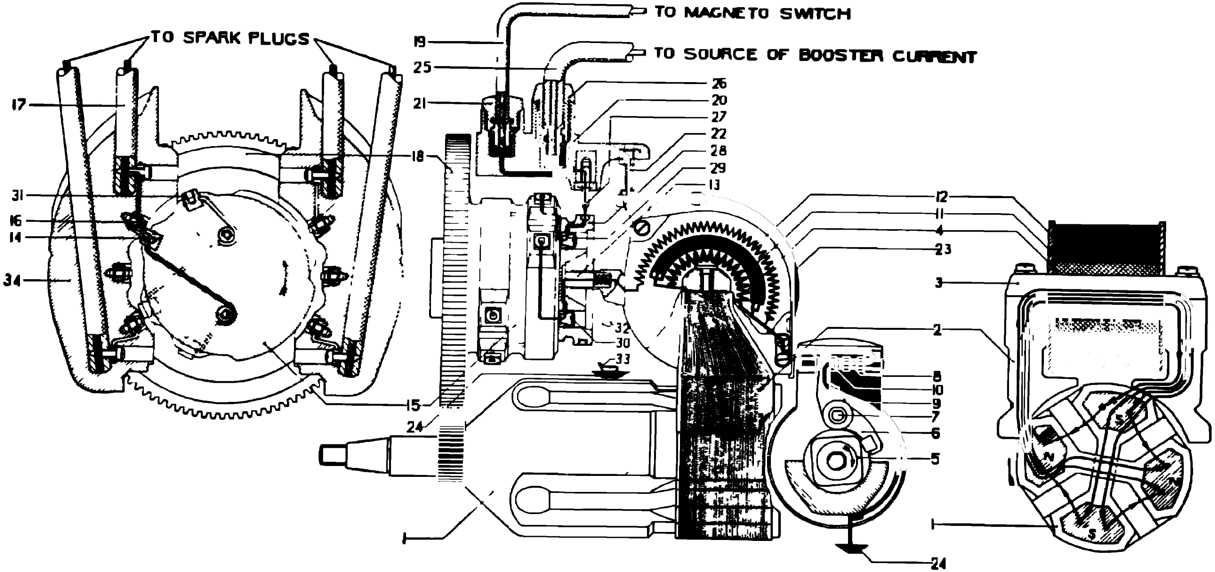
The rotating magnet (1) revolves between the laminated pole shoes (2), producing an alternating field in the core of the coil (3).

When the current reaches its maximum value, the breaker cam (5) causes the breaker lever (6) to turn on its axle (7), thus opening the platinum contact points (8) and (10).

The cam (5) is mounted on the rear end shaft of the rotating magnet (1), its position being fixed in relation to the magnetic field.

The short contact screw (10) is connected to the ground (24) through the breaker lever (6) and the main spring for breaker lever (9); the long contact screw (8) screws into the insulated support and maintains permanent contact with the primary winding (4) by means of a laminated copper brush fastened on the primary bridge (23). Therefore, when the contact points (8) and (10) are open, the circuit current is suddenly interrupted.

High-Tension Current.—The interruption of the primary current induces a high-tension current in the secondary winding (12) composed of a large number of turns of fine wire. One end of the secondary winding (12) is connected to the ground (24) through the primary winding (4) and the core of the coil (3); the other end terminates at the high-tension carbon brush holder which is built in as an integral part of the coil.



1 Rotating Magnet
2 Pole Shoes
3 Core of Coil
4 Primary Winding
5 Breaker Cam
6 Breaker Lever
7 Breaker Lever Axle
8 Long Contact Point (Insulated)
9 Main Spring for Breaker Lever
10 Short Contact Point
11 Condenser
12 Secondary Winding
13 High Tension Carbon Brush
14 Segment in Distributor Cylinder carrying Secondary Current
15 Distributor Cylinder
16 Electrode in Distributor Block
17 Ignition Cable
18 Large Distributor Gear
19 Ground Wire
20 Booster and Ground Connection Block
21 Fastening Screw for Ground Wire
22 Stud for Ground Contact
23 Primary Bridge
24 Ground through the Magneto and Engine
25 Booster Cable
26 Fastening Screw for Booster Wire
27 Electrode for Booster Current
28 Collector Ring for Booster Current
29 Fastening Screw for Collector Ring (in Booster Circuit)
30 Fastening Screw for Collector Ring (in Secondary Circuit)
31 Segment in Distributor Cylinder carrying Booster Current
32 Safety Gap Electrode
33 Ground Plate for Safety Gap
34 Distributor Block

FIG. 44.—Diagram of Electric and Magnetic Circuits.

The Condenser (11) is connected in parallel with the contact points (8) and (10). It prevents abnormal arcing at the points when the primary current is interrupted, thus reducing their wear to a minimum and insuring regular sparking.

Distributor.—The high-tension carbon brush (13) transmits the current to the spark plugs through the medium of the distributor cylinder (15) and distributor blocks (34) and the ignition cables (17).

The high-tension brush (13) bears on the central contact of the collector ring for booster current (28) which is secured to the distributor cylinder (15) by two fastening screws (29) and (30). The screw (30) is located in the secondary current circuit and connects the central contact in the collector ring for booster current (28) with the conductor molded into the distributor cylinder (15) and leading to segment (14).

The distributor cylinder (15) is fixed on the large distributor gear (18) in a definte position relative to the opening of the contact points (8) and (10) and for a given rotation, which in the diagram is anti-clockwise. Thus the segments (14) successively register with the electrodes (16) in the distributor blocks (34), thereby transmitting the secondary current to the ignition cable (17) and thence to the spark plugs.

Safety Gap.—The safety gap is the space between the insulated electrode (32) which screws into the high-tension carbon brush holder and the electrode (33) on the safety-gap ground plate. Its function is to protect the coil against excessively high voltage by providing a means of escape for the charge, which will jump the gap between the electrodes (32) and (33) in the event of the secondary circuit being accidentally broken between the plugs and the coil.

Advance and Retard.—The advancing and retarding of the ignition is obtained by moving the breaker assembly about the cam (5). Moving the breaker assembly against the direction of rotation of cam (5) gives advance; moving breaker assembly with direction of rotation gives retard.

Booster Connection for Starting.—The booster cable (25) is held by fastening screw (26). The booster current is carried to the electrode for booster current (27) through the medium of a conductor molded into the dielectric material of the booster and ground connection block (20), thence through a small air gap to the collector ring for booster current (28). The fastening screw for collector ring (29), located in the booster current circuit, transmits the booster current to the segment (31) in the distributor cylinder (15). The booster current then jumps the air gap to the nearest electrode in the distributor block (34) and thence through the ignition cable (17) to the spark plug. The booster

current segment is located in such a manner that it trails the secondary current segment (14).

Stopping the Engine.—To stop the engine, the ignition is cut out by neutralizing the functioning of the contact points (8) and (10). This is accomplished as follows: The end of the primary winding (4) terminates through the spring contact on top of the primary bridge (23) and thence through the stud for ground contact (22) to the primary terminal marked *P* and carrying the fastening screw for ground wire (21). The ground wire (19) goes to a switch located conveniently for the pilot. When the switch is closed, the effect of the contact points (8) and (10) is neutralized by permitting the primary current to flow around the points and through the switch to the ground, thus grounding the primary current and causing the ignition to cease.

Installing.—Make sure that the magneto shaft half of the drive coupling is seated and keyed on taper of drive shaft and then locked by nut and washer and safetied with a cotter pin. Spin magneto and note that drive shaft half of coupling runs true.

Inspect magneto base. See that the $\frac{3}{8}$-16 threads in the hold-down holes have not been stripped or that the start of the thread has not been closed, thus having a tendency to cause cap screw to cross threads. When necessary, clear up threads with a $\frac{3}{8}$-16 tap and then clean holes thoroughly.

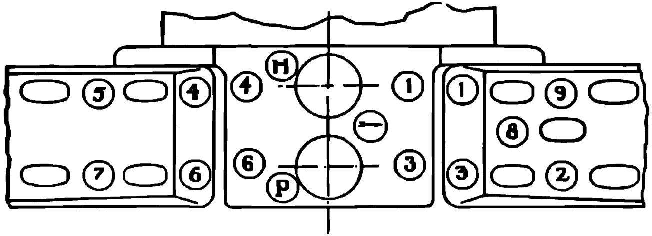
Note dowel-pin holes. They should fit the pins very snugly but not so tight as to cause difficulty in getting the magneto down on the surface of its support. See that the base of the magneto is smooth and makes good contact with the bracket surface.

When the mechanic has made use of the above instructions and any other information that he has found to be helpful from previous installations of this nature, the magneto is ready to be secured.

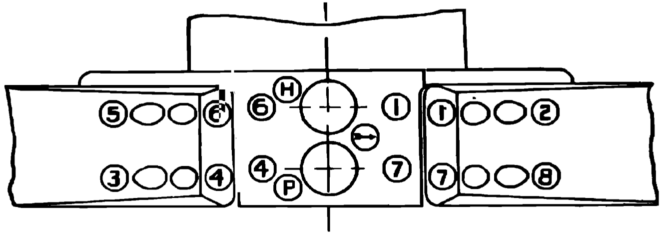
It is imperative that the length of the $\frac{3}{8}$-16 cap screws be correct. When in doubt as to correct length, it can best be obtained by direct measurement.

Making allowance for the thickness of the washer used on the screw, the length must be such that when the screw is tight, it will not have less than $\frac{7}{16}$ or more than $\frac{1}{2}$ in. of its threaded length in the $\frac{3}{8}$-16 hole in the base of the magneto. When the correct length is established draw the screws up tight and safety.

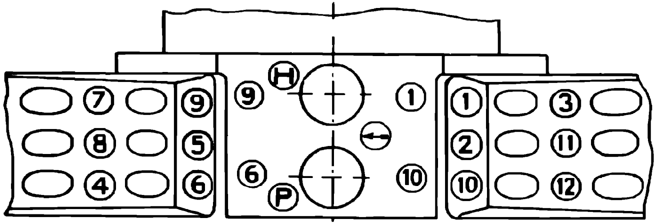
Timing.—Turn engine slowly as piston in cylinder No. 1 comes up on compression. Stop when the full-advance position for the ignition, as given by the engine manufacturer, is reached. This point is given in degrees before top center and is marked on the timing disc to be used with the engine.



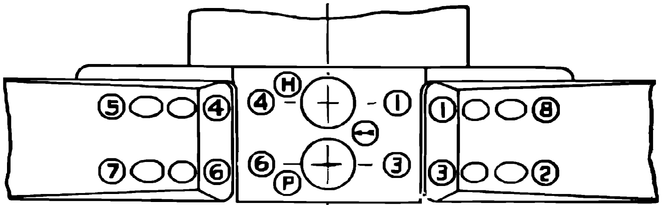
Connection Diagram of the AG 9-D Clockwise Rotation.



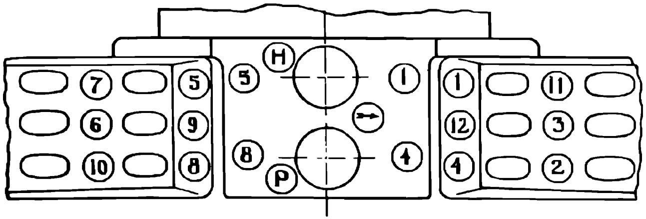
Connection Diagram of the AG 8-D Anti-clockwise Rotation.



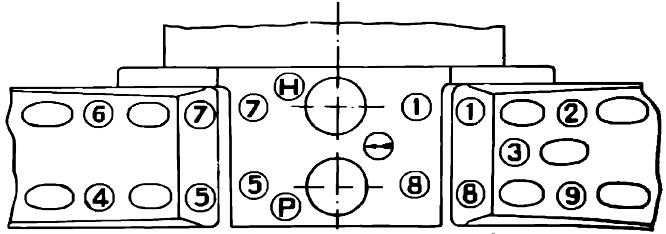
Connection Diagram of the AG 12-D Anti-clockwise Rotation.



Connection Diagram of the AG 8-D Clockwise Rotation.



Connection Diagram of the AG 12-D Clockwise Rotation.



Connection Diagram of the AG 9-D Anti-clockwise Rotation.

Fig. 45.—Connection Diagrams from Drive Shaft Ends.

At this point the magneto is to be coupled to the engine through the timing window located under the front oil-hole cover. When this No. 1 is in line with the white mark at the top of the timing window it indicates that the contact points are at the instant of opening with the breaker fully advanced, and that the No. 1 electrode on the distributor block is registering with the proper segment on the distributor cylinder. Some installations do not permit of this window being used. In such cases the supplemental timing marks must be used. They are located on the inside surface of the large distributor gear and the front end plate and are so arranged that when they coincide with one another the contact points are at the instant of opening.

Fasten the spark-plug cables to the distributor blocks. The numbers on the distributor blocks show the serial firing order of the magneto. The numbers on the top of the main cover are for the purpose of locating the right and left distributor blocks to their respective sides.

Observe that each magneto is wired to its proper set of wires as given by the engine manufacturer and that the wires lead from the magneto so that No. 1 on the distributor block goes to No. 1 or first cylinder in the firing order of the engine, No. 2 on the distributor block goes to the second cylinder in the firing order of the engine, No. 3 on the distributor block goes to the third cylinder in the firing order of the engine, etc., until all cylinders have been wired in their proper firing order. Clamp distributor blocks in place.

The letter *H* marks the terminal to which the booster wire is to be connected.

The letter *P* marks the terminal to which the ground or short-circuiting wire from the magneto switch is to be connected.

The arrow indicates direction of rotation of the magneto when viewed from the drive end.

Tighten and lock the drive coupling. The advance lever linkage is to be connected to the advance lever on the magneto, special attention being given that full advance and retard are obtained when the spark lever in the cockpit is moved to its full advance and retard positions.

SPECIAL INSTRUCTIONS

Changing Direction of Rotation.—Disassemble magneto. Pull the cam and observe the small *D* and *G* stenciled on the face of the breaker end shaft. Assuming that this is to be a change of rotation from anticlockwise to clockwise, remove Woodruff key from keyway marked *G* and replace in the one marked *D*. Replace cam and pull cam fastening screw up tight.

Remove distributor cylinder and then the large distributor gear. Remove small dog screw from G (*within the circle*) and replace in threaded hole marked D. Lock end of dog screw in face of distributor gear.

Note that G (*without* a circle around it) is to be used only when the magneto is for anti-clockwise rotation **and has no booster connection.**

Remove the timing window and the supplemental timing marks on the inside surface of the front end plate.

Replace large distributor gear and distributor cylinder. The distributor cylinder is now in the correct position for right-hand rotation.

Observe that the collector ring for booster current has a D and G on its face, located 180 degrees from each other. There is a mark on the inside face of the distributor cylinder with which either the D or G must line up, depending upon the direction of rotation.

Remove collector ring for booster current and turn it so that D is in line with the mark on the inside face of distributor cylinder. Replace and fasten collector ring for booster current to distributor cylinder with fastening screws provided for it.

Remove end cover with advance lever from breaker assembly. Unscrew dog-plate fastening screws and remove dog plate. Now carefully lift the bayonet lock latch and spring off breaker cage. Remove the bayonet lock spring from the bayonet lock latch, turn it over and put it back in place. This is done in order that the lock spring may hold the breaker assembly in full advance.

The contact breaker lever axle and breaker lever are to be removed. This permits of an easy exchange of locations for the fiber stop and the long contact screw. Remove long contact screw and fiber stop and replace each one in the opposite hole.

Reverse contact breaker lever and replace so that the contact points match.

Screw breaker lever axle in tight and lock threaded end to breaker cage.

Now replace bayonet lock latch spring. Note that each end of the spring is secured. One end fastens in bayonet lock latch and the other or inside end fastens in breaker cage.

Replace dog plate and secure with dog-plate fastening screws. Lock screw heads to dog plate.

Fasten end cover with advance lever in place, and the breaker assembly is ready for clockwise rotation.

Recharge rotating magnet; note that it is clean and free from clinging metal particles and replace in magneto housing. Turn magnet until marked tooth on distributor gear is up.

Take front end plate and put in position for matching gears. Turn large distributor gear until tooth marked *D* lines up with marked tooth on distributor gear. Mesh gears and slide front end plate into place and fasten to magneto housing with nuts and screws provided.

Replace contact breaker assembly. Turn rotating magnet until the number *I* on the distributor gear appears in the opening for the timing window in the front end plate.

Now hold the rotating magnet so that the contact points are just at the instant of opening, and then replace the timing window so that the white mark therein will coincide with the mark on the large distributor gear directly above the number *I*.

Provide the front end plate with new supplemental timing marks that will coincide with the original marks on the distributor gear. The new marks will be correct for clockwise rotation of magneto.

Replace main cover and change rotation-indicating arrow from anti-clockwise to clockwise rotation.

Change number discs to correspond with clockwise rotation as shown in distributor block diagrams and replace distributor blocks.

The magneto is now ready for test as a clockwise (right-hand) rotating magneto.

If it is required that the direction of rotation of the magneto be changed it is strongly recommended that the magneto be sent to the Scintilla factory for this purpose.

Adjusting End Play of Rotating Magnet.—As there is only 0.002 in. air gap between the rotating magnet and the pole shoes, and in consideration of the design of the ball bearings, it is imperative that there be a careful adjustment of the axial or end play of rotating magnet between its bearings.

Since the rotating magnet exerts a certain amount of attraction between its poles and the pole shoes, when turned from the neutral position, advantage is taken of this pull to get the correct adjustment of the ball bearings.

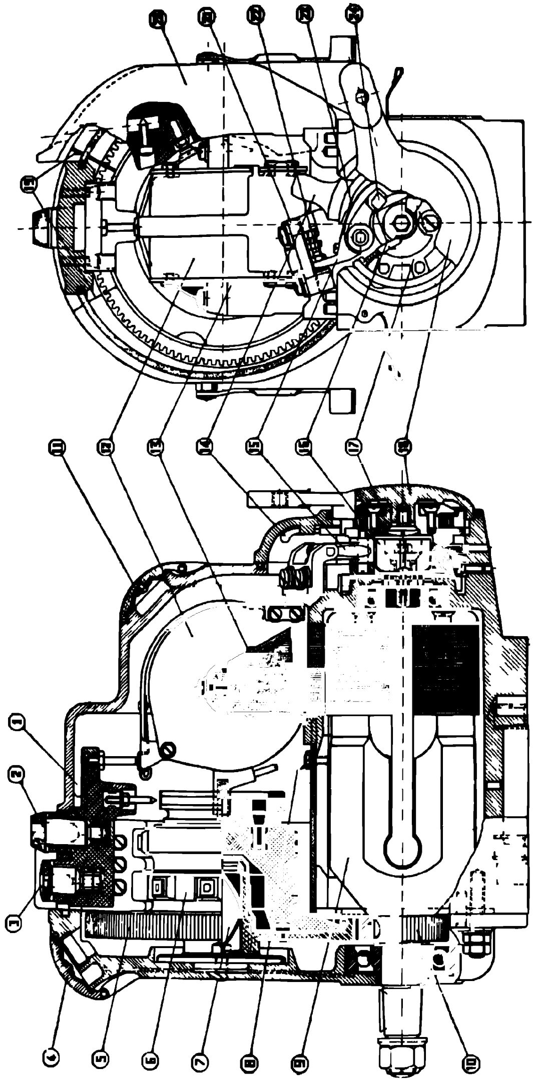
The end-play adjustment is really carried beyond the point where a mechanic could actually feel even the slightest hint of end play.

The correct adjustment is observed by turning the rotating magnet away from its neutral position and noting how far the trailing edge of the rotor slot can be from the edge of the opening between the pole shoes and still return to its neutral position.

Obviously, the closer the edge of the slot must be to the pole shoe edge in order to pull back to neutral, the tighter the bearings.

It has been found in practice that when the distance between the

pole shoe edge and the rotor slot edge is from $\frac{3}{8}$ to $\frac{3}{4}$ in., the adjustment is satisfactory, while $\frac{5}{8}$ in. is the desirable adjustment.



1 Booster and Ground Connection Block
2 Fastening Screw for Booster Wire
3 Fastening Screw for Ground Wire
4 Front Oil Hole and Timing Window Cover
5 Distributor Gear
6 Distributor Cylinder
7 Distributor Gear Axle
8 Safety Gap
9 Rotating Magnet
10 Small Distributor Gear
11 Rear Oil Hole Cover
12 Coil
13 Laminated Pole Shoes
14 Bayonet Lock Latch
15 Contact Breaker Lever
16 Cam
17 Dog Plate
18 End Cover with Advance Lever
19 Timing Marks
20 Distributor Block
21 Insulated Support
22 Contact Points
23 Breaker Lever Main Spring
24 Cam Follower

FIG 46 —Sectional Drawing of Scintilla Aircraft Magneto.

The adjustment of the end play is obtained by means of steel spacing washers which fit in between the inner ball races and the rotating

magnet. Keep the total thickness of spacing washers just as nearly equal as possible on each end. These spacing washers come in thicknesses of 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 mm., which is approximately 0.002, 0.004, 0.008, 0.012, 0.016, and 0.020 in., respectively.

Installing Outer Bearing Races.—The outer bearing races in the Scintilla Aircraft Magnetos are insulated from the magneto by insulating strips of a specially prepared material. They are also backed by washers of this material, which is very rigid and will stand considerable pressure.

Thus the ball bearings are free from minute electric arcing which causes the balls to turn black and promotes excessive wear. These ball races are readily removed by a specially designed puller and are easily pressed in by another tool.

There is a recess cut in the metal where the outer races fit. This recess allows the overlapping of the ends of the insulating strip. There is another recess cut in the metal back of the insulating washer; it is for oil.

In installing an outer race, first put the washer in so that the cut in it will line up with the oil recess. Then spread a few drops of oil evenly over one side of the insulating strip. Take strip up and bend it in a circular form, with the oiled side inside, and overlap the ends enough to allow the strip to fit easily into the container for the outer race. When it is released, it will expand against the container walls and the ends will overlap slightly in the recess cut for them.

Place outer race squarely inside the insulating strip and press until race seats against insulating washer. The race should have a slight press fit which may be obtained by the selection of insulation strips of proper thickness. Great care must be exercised in keeping in line the race and the front end plate, or the race and the magneto housing, as the case may be, so that the race will not cut the insulating strip, or, by not being seated squarely, cause serious injury to the ball races or the cage and the ball assembly.

Contact Points.—The life of the contact points depends to a great extent on how clean they are kept. Therefore, take particular pains to keep them as clean as possible. File them only when it becomes absolutely necessary for the best operation of the magneto.

The gap between contact points when fully opened should be maintained at 0.012 in. Use the gage on the Scintilla wrench for this purpose. Keep points in alignment.

Adjusting Fiber Stop.—The fiber stop is mounted in the insulated support just back of the top of the breaker lever. Its function is to limit the travel of the breaker lever at high magneto speeds.

The fiber-stop clearance is measured between the face of the stop and the back of the breaker lever. The clearance must be measured with the points fully opened. The fiber-stop clearance must not be less than 0.002 in. This may be obtained in a practical way by using a 0.002-in. feeler, placing it behind the breaker lever and turning the rotating magnet until the points are at their maximum opening. The tension on the feeler, as it is pulled from between the back of the breaker lever and the fiber stop, should be just enough to allow it to be withdrawn easily.

Care should be taken in filing stop so that when proper clearance is obtained and the breaker lever is pushed back against the stop the whole surface of the stop bears against the back of the breaker lever.

It is impracticable to state a maximum fiber-stop clearance which could be applied impartially to all Scintilla Aircraft Magnetos, inasmuch as the fiber stops and cam followers and contact points do not wear exactly alike.

Distributor Block Electrode Clearance.—There will be very little necessity for putting in new electrodes in the distributor blocks. However, should it become necessary, it is very important that they have the correct clearance. The minimum clearance should be 0.030 in. The maximum clearance should not be over 0.050 in. Templates for measuring these clearances may be obtained from the manufacturer.

Adjusting Mesh of Large Distributor Gear.—This adjustment will rarely be found necessary. In the event that the large distributor gear requires replacement, adjust gear as follows:

To raise gear, loosen fastening screws on distributor gear axle flange and drift axle slightly to the right as viewed from the distributor-gear side of the front end plate.

To lower gear, drift axle slightly to the left.

Tighten fastening screws for distributor-gear axle and lock outer ends to outside surface of front end plate.

Timing Magneto by Means of Lights.—This practice can be followed very easily while the magneto is on the repair bench and the coil is not installed, and will serve as a very accurate means of checking the internal timing of the magneto.

Once the coil is installed, however, and the magneto is mounted on the engine, the timing marks of the magneto will be found sufficiently accurate to meet all practical requirements for timing the magneto to the engine.

With the coil in place, the internal circuits and construction of the magneto are such that if an external source of current is applied to the contact points, there is the danger of the coil acting as an electromagnet

and weakening the magnetic qualities of the rotating magnet, thus impairing the efficiency of the magneto.

Oiling the Magneto.—Proper oiling is of vital importance for the satisfactory operation of the magneto. Use the best grade of medium-bodied oil obtainable.

Put from 30 to 40 drops of oil in the front oil holes or until it appears at the overflow hole for the distributor-gear axle bearing. This hole is located about an inch below the front oil-hole cover.

Put about 3 to 5 drops of oil in the back oil hole.

Note that the felt wick in the bottom of breaker cage is thoroughly saturated with a heavy-bodied oil.

Oil magneto thereafter at regular intervals of about 25 hours of service.

"BOOSTER" MAGNETOS

Because of the ignition magnetos producing a weak spark at engine cranking speeds, a "booster" magneto is sometimes provided to augment

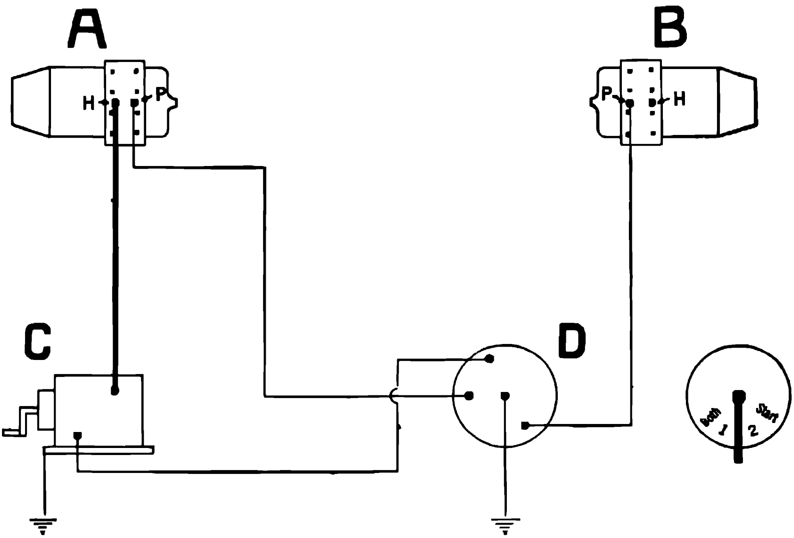


FIG. 47.—Booster Magneto Hook-up.

(*A*) & (*B*) Main Ignition Magnetos.
(*C*) Booster Magneto.
(*D*) Rear of Switch.

the main ignition magnetos. The "booster" magneto may be hand-cranked, or provision is sometimes made to drive this magneto off the engine starting crank. "Booster" magnetos are high-tension mag-

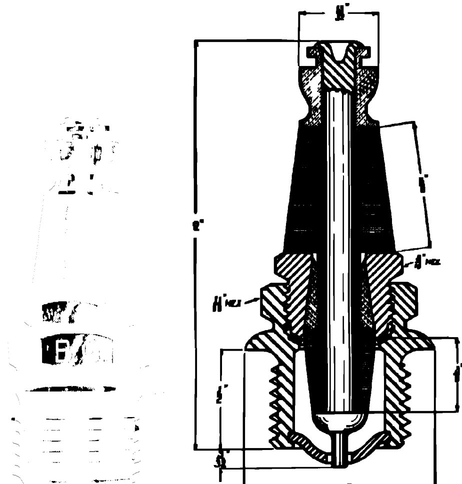
netos without a distributor, the high-tension current generated by the magneto being conveyed to the distributor of one of the main magnetos for distribution during the process of starting the engine.

The "booster" magneto furnishes a shower of sparks of an intensity sufficient to facilitate engine starting. This current enters one of the main magnetos at a provided terminal, which is designated by the letter *H* on the Scintilla Magneto. The "booster" magneto requires little attention aside from an occasional drop of oil on the gear bearing and a cleaning of the breaker contacts.

AC Spark Plugs

SPARK PLUGS

B. G. Hornet Spark Plugs.—The B. G. Hornet spark plug has mica for its insulation. Mica as an insulator has some outstanding characteristics. It has a very high dielectric strength. It withstands very high temperatures and is unaffected by sudden changes of temperature. Mica-insulated B. G. spark plugs are made for both air- and water-cooled aircraft engines. The threaded part is the regular aviation standard metric thread, 18 mm. in diameter, 1.5-mm. pitch and $\frac{1}{2}$-in. (12.7 mm.) reach.



B. G Spark Plugs.

Fig 48.

The type numbers of B.G. plugs designate the amount of mica on the core which is exposed to the cylinder temperature. The more mica exposed, the hotter the plug will run. Broadly classified, the Hornet type numbers are employed as follows: No. 2 for extra high-

compression engines, as for example 8 : 1 water-cooled engines; No. 3 for high-compression engines, as for example 6.5 : 1 water-cooled or 6 : 1 air-cooled; No. 4 for the usual ratios such as are used for the majority of aircraft engines, for example, the Curtiss D-12, Packard 1500 water-cooled V-types, and the air-cooled radial engines built by the Pratt & Whitney and Wright Companies.

B. G. Model 1XA Regular.—The model 1XA regular B. G. spark plug is used for all engines, both air- and water-cooled, employing moderate compression ratios. It is of two-piece construction like the B. G. Hornet, and can readily be taken apart for inspection or cleaning. The best results are obtained when the spark gap is maintained at 0.015 in., and when, after long use, the gap becomes greater than this, it can readily be restored by moving the side electrode either with a small punch or with a special gap-setting tool.

The model 1XA regular plugs have been used on such engines as the Liberty, Curtiss D-12, C6, K6, OX, Wright Whirlwind, Pratt & Whitney, Hispano-Suiza, and similar engines. The thread is 18 mm. in diameter, 1.5-mm. pitch, and ½-in. (12.7 mm.) reach.

AC Spark Plugs.—AC spark plugs are obtainable in three successful types for aircraft engines. The AC Type N, known as Metric Aircraft (Regular), is recommended for air-cooled engines operating at cruising speeds, or where continuous fouling is experienced with type NN-1 or pre-ignition with type N-1. The AC plug Type N-1, known as Metric Semi-Aircraft (Modified Aircraft), is recommended for water-cooled engines, or in air-cooled engines where fouling is experienced with type N. AC Type NN-1, known as Short Metric Aircraft, is recommended for air-cooled engines operating at full throttle over long distances, or where pre-ignition is experienced with type N.

CHAPTER VI

CARBURETION

√Although the fundamental principle of all carburetors is simple, yet simplicity has not always been true of some carburetor construction. It should be encouraging to those who have puzzled over various makes to witness the tendency of present carburetor manufacturers to market uncomplicated designs having few moving parts and few external adjustments. However, the carburetor which answers modern requirements and also has few parts involves deeper theory than many of the more complex-appearing devices.

To gain a clear conception of what takes place in any type of carburetor, it first is necessary to understand what mixtures are desired under varying conditions and how they can be obtained. Regardless of how a carburetor of a given make appears to the eye and regardless of the construction followed, the fact must be realized that all carburetors are designed to attain the same end, which is to supply a mixture of gasoline and air that will be as close as possible to the correct mixture demanded at different engine speeds.

There is little misunderstanding about the vacuum which is created during the downward movement of the piston on the inlet stroke, or how it draws gasoline from the spray nozzle and mixes the liquid fuel with the air around and above the spray nozzle. The misunderstandings arise as the result of the great number of ideas which have been embodied in various designs to take care of the varying mixtures an engine requires at different engine speeds.

The defects of what is generally referred to as a simple carburetor and the variable demands of a high-speed engine are the first steps for mastery in the study of carburetion. It should first be clear in mind that any hydrocarbon engine that is intended to run at a constant speed, whether low or high, could be supplied with a combustible mixture by any simple arrangement of a hole for air and a hole for gasoline of the correct size to give the proper proportion of gasoline and air for that one engine speed. For instance, an ordinary inlet manifold with the opening for the carburetor sealed and with a hole drilled into

the manifold would be sufficient. By placing a funnel in the hole, gasoline could be poured into the manifold in small quantities, and this arrangement would serve as a carburetor if the necessity arose. However, such an arrangement would provide no means of throttling the engine except by cutting off the fuel. To pour gasoline through the funnel in the exact proportion demanded by the engine at different speeds would be impossible, but it is just this task which the carburetor is required to perform.

We next have to grasp the construction of a device which will automatically supply a liquid fuel to the engine. A simple carburetor, regulating in some degree the flow of gasoline and air to the engine, would consist of a float in a float chamber for maintaining a level of gasoline in the spray nozzle, and the spray nozzle placed directly in an air passage between the atmosphere and the combustion chamber of the engine, and a throttle placed in the passageway to control the speed of the engine by a control of the suction. Such an arrangement is shown in Fig. 49, and represents the basic principle of all conventional carburetors. In other words, this is the principle of all carburetors stripped of their refinements. This simple device has its defects, of course, or there would be no necessity for further complication.

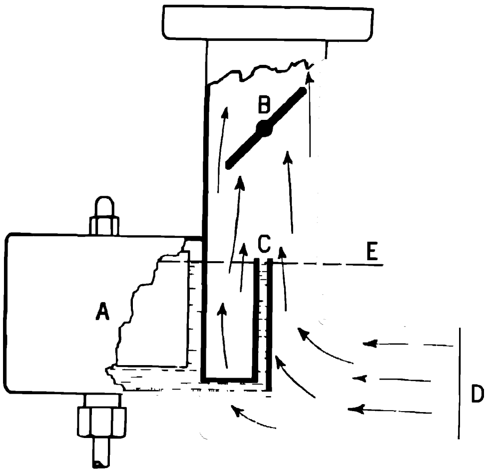


FIG. 49.—Simple Type Carburetor.

(A) Float in float chamber
(B) Throttle butterfly valve
(C) Spray nozzle
(D) Air inlet
(E) Gasoline level

The defects of the *simple carburetor* lie in its failure to give a mixture of correct proportions under varying suctions to which it is subjected at variable engine speeds. If the opening for air and the opening for gasoline are of the proper size to give a correct mixture for low engine speeds, the mixture will become too rich with gasoline at high engine speeds. Under increased suction the liquid fuel will flow faster from the spray nozzle than the flow of air through the inlet pipe, resulting

in a mixture which becomes too rich when high engine speeds are reached. This is a law of liquid flow in relation to the flow of air which cannot be denied, and yet its effect can be counteracted, and the first step in correct carburetor designing is to provide a means to counteract this defect of the *simple carburetor.*

It must next be realized that the variable speed of the engine calls for variation not only in the quantity of gasoline and air, but likewise in the proportion of gasoline and air. At low engine speeds the throttle in the carburetor is almost closed, and the restricted opening prevents all of atmospheric pressure from entering the inlet manifold and combustion chamber. A lowered compression in the engine is the result of the restriction at the partly closed throttle. Lowered compression is a direct loss, and in addition there is a slight loss of compression past the slow-moving pistons, for slow-moving pistons permit time for compression to find its way past the pistons. During the slow ascent of the pistons on compression strokes there is also some loss of compression heat to the cylinder walls. These losses when combined create, in order to sustain combustion, a demand for a mixture which is rich in gasoline. As the throttle is opened to increase the speed of the engine, these losses diminish, and the mixture must become leaner, for the increased piston speed creates a demand for a lean mixture, which is a fast-burning one.

Comparing the variations in engine demands and the variations in mixture provided by a *simple carburetor,* it will readily be realized that the demands of the engine for a leaner mixture as its speed increases is the *opposite* to the mixture given by the *simple carburetor* under the same conditions. The engine demands a rich mixture at low speeds and a lean mixture at high speeds. The *simple carburetor* starting out with a rich mixture, or correct mixture, at low speeds, provides an excessively rich mixture at high speed. Therefore, as it is the engine which must be satisfied to gain efficiency, the carburetor must be so constructed that such defects will be counteracted, or, in other words, reversed.

The carburetor is handling liquid fuel and air; therefore, there are but two principals to control. With the proportions of gasoline and air correct at low speeds and too rich at high speeds, there are but two possible means of keeping the proportion nearly constant. First, the flow of gasoline may be decreased, and second, the flow of air may be increased. This change either of air or gasoline to bring about a leaning down of the mixture as the engine speed increases is called *compensating the carburetor.* It is to attain this end that carburetors of various designs have been developed, some accomplishing

their purpose by means of increasing the flow of air and others by decreasing the flow of gasoline.

Compensation has been accomplished in many ways: by the well-known auxiliary air valve which dilutes the mixture as the engine speed increases; by a compound nozzle consisting of two jets, one which grows richer as the speed is increased, the other growing leaner. Thus one counteracts the defect of the other, giving a mixture of constant proportion. Compensation has successfully been accomplished by the *air bleed* principle, and many other methods have been used with more or less success, but the point must not be lost sight of that they are all designed to give a mixture demanded by the engine and counteract the defects of a *simple carburetor.*

Carburetion theory, then, may be condensed into five rules. as follows:

Rule 1.—If a *simple carburetor* has the correct opening in the spray nozzle and the correct air opening to furnish the right proportion of gasoline and air at low engine speed. it furnishes a mixture too rich at high engine speeds.

Rule 2.—At low engine speeds, the restricted throttle opening lowers compression; compression is also lost past the slow-moving pistons, and compression heat is lost to the cylinder walls. These losses at low engine speeds cause the engine to demand a rich mixture to sustain combustion.

Rule 3.—At high engine speeds the losses are not so great in the engine, and a leaning down of the mixture not only becomes possible but is advantageous, as a lean mixture is faster burning and more economical.

Rule 4.—The demands of the engine are variable from low speed to high speed, a rich mixture being required at low and a lean mixture at high speed. The mixture given by a *simple carburetor* is also variable from low speed to high speed but is the *opposite* of that required by the engine. Therefore, there must be some means provided to reverse or counteract the variation of the carburetor mixture.

Rule 5.—To obtain the necessary leaning down of the mixture as the engine speed increases, the gasoline flow must be *reduced* or the flow of air *increased.* Any method used to obtain this end is termed *compensation* or *compensating the carburetor.*

The foregoing rules cover the principles of mixtures. To involve figures relative to mixture proportions leads toward confusion, for it is not possible, under ordinary conditions, to determine the exact mixture proportions, nor is it necessary. Close figures are confined to laboratory work, and it suffices here to state that an engine will run on a few parts

of air to one part of gasoline, operating under certain conditions on as great as eighteen or nineteen parts of air to one part of gasoline. These are the extreme limits of mixtures on which an engine will run. Near these limits are proportions of gasoline and air on which an engine will run efficiently. Practical tests are all the student or mechanic has at his disposal, as is explained further on in this discussion.

In Fig. 49, a *simple carburetor* is shown of which defects have been explained. In Fig. 50, an auxiliary air valve has been added to the *simple carburetor* to compensate for its defects. Normally, the attached air valve is closed and held to its seat by a spring which has enough tension to prevent the valve from being drawn open until the increased vacuum in the mixing chamber of the carburetor begins drawing too much gasoline from the spray nozzle. When the vacuum above the spray nozzle reaches a degree at which more gasoline would be drawn from the spray nozzle than is required, the air valve is sucked open, allowing additional air to enter above the spray nozzle and thus dilute the mixture by relieving the vacuum.

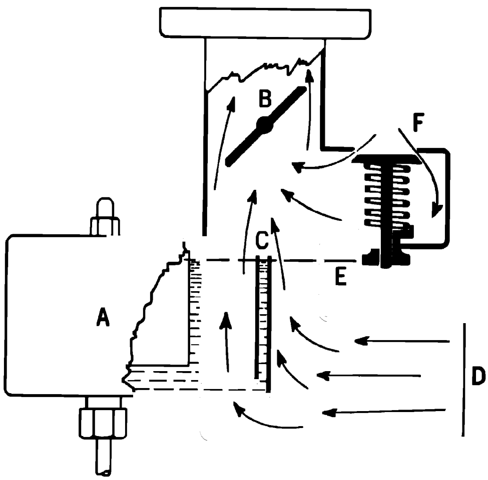


FIG. 50—Addition of an Auxiliary Air Valve to a Simple Type Carburetor

(A) Float in float chamber
(B) Throttle butterfly valve
(C) Spray nozzle
(D) Air inlet
(E) Gasoline level
(F) Auxiliary air valve

As the throttle is opened and suction upon the spray nozzle increases, the air valve is automatically opened further to prevent the mixture from becoming too rich under the increasing suction. It is obvious that with a weak spring on the air valve the mixture would become too lean at all speeds. The valve would open too soon at low speeds and for all speeds of the engine above low speed. To make the air valve adaptable for different engines and climatic conditions, and to compensate for wear or lost spring tension, an adjustment is provided upon the air valve to change the spring tension. To make the carburetor adaptable for different makes of engine and climatic conditions an

adjustment to vary the flow of gasoline may also be provided for the spray nozzle, as shown in Fig. 51.

The carburetor as shown in Fig. 51 has been given additions until it approaches the design of some modern models. With such a device upon an engine, and the gasoline spray nozzle and the air valve adjusted for the best results, good performance would be obtained if a very volatile gasoline were used. On the other hand, with heavier fuel the process of vaporization would demand more heat than the atmosphere entering the air passages would provide.

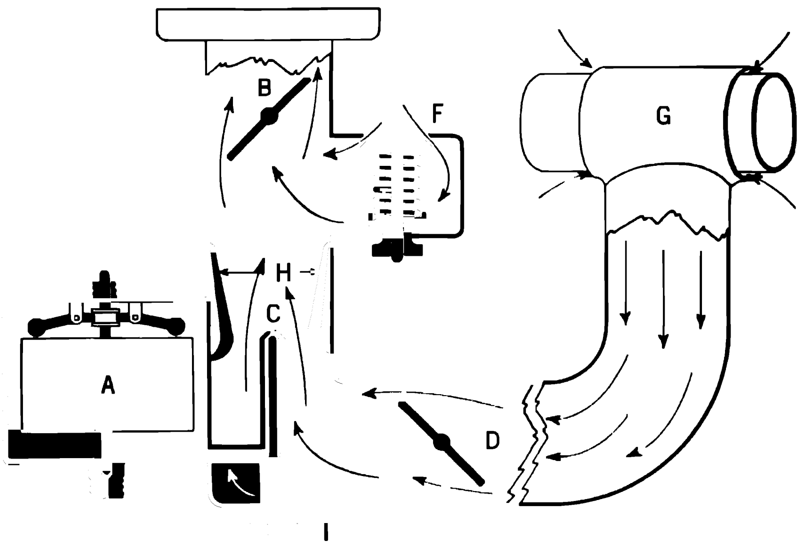


FIG 51 Carburetor Adjustments

(*A*) Float in float chamber
(*B*) Throttle butterfly valve
(*C*) Spray nozzle
(*D*) Choke butterfly in primary air inlet
(*F*) Secondary or auxiliary air valve
(*G*) Hot air stove about exhaust pipe
(*H*) Venturi tube
(*I*) Needle valve in spray nozzle

Vaporization is accomplished in the mixing chamber of the carburetor by the reduced pressure of suction. Heat is absorbed by the process, and at such a rapid rate that the temperature within the mixing chamber becomes very low. The available heat in the carburetor casting would soon be absorbed, vaporization would be reduced and might cease entirely, if atmospheric temperature were extremely low.

To provide the necessary heat for the process of vaporization, a water jacket was adopted early in carburetor history. The water jacket placed around the carburetor was connected by pipes with the water

circulating about the cylinders of the engine in such a manner that a portion of the heated water leaving the water jackets about the cylinders circulated through the carburetor water jacket.

The hot-water jacket around the carburetor was found to be inadequate when the gasoline on the market became heavier, resulting in a corresponding demand for more heat. When the atmospheric temperature was low in winter, the air entering the air passages of the carburetor was so cold that the process of vaporization was again interfered with and led to the adoption of applying warm air in conjunction with the hot-water jacket, as shown in Fig. 52.

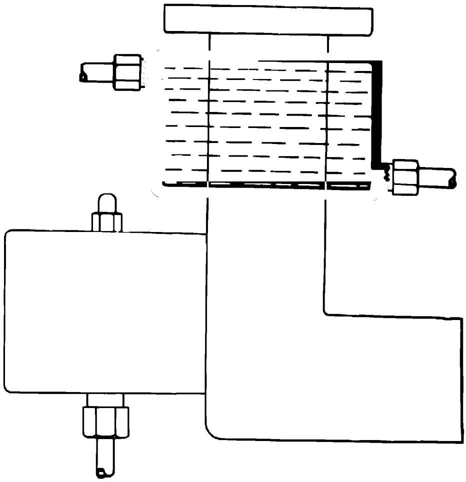


FIG. 52.—Application of Hot Water to Carburetor.

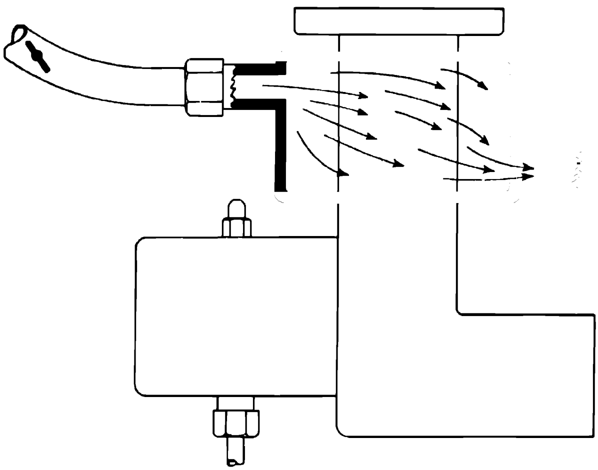


FIG. 53.—Application of Exhaust Heat to Carburetor.

The well-known carburetor air heater placed near or about the exhaust manifold served well for several years when the hot-water

jacket around the carburetor was also used, but it should be clearly understood that such a heating arrangement is not always sufficient with ordinary gasoline. Too much reliance is put upon the air heater, and serious troubles arise when an engine so equipped is operated during the winter months in northern countries, or at very high altitudes.

The hot-water jacket has been successfully supplanted by an arrangement shown in Fig. 53, or a similar application, which is nothing more than directing the exhaust heat upon the carburetor casting in place of hot water. As it is desirable to introduce the mixture into the engine as cold as possible without sacrificing vaporization, there is a limit to the amount of heat which can be employed in this manner. The arrangement shown in Fig. 53 is capable of supplying an excessive amount of heat under wide-open throttle conditions, and to prevent this, one well-known carburetor manufacturer provides a butterfly valve in the passageway from the exhaust manifold, so that the exhaust heat is automatically reduced as the throttle is opened, the valve opening again as the throttle is closed to compensate for the reduced heat in the exhaust manifold under small throttle openings. This arrangement is intended to maintain a constant heat application upon the carburetor. If the cut-off for the heat was not provided, the mixture would be overheated at wide open throttle, and the mixture would be expanded within the manifold to such a degree that a marked drop of the charge reaching the combustion chamber would result.

Similar to the application of the exhaust to the carburetor is the popular *hot spot manifold*. By combining the exhaust and inlet manifolds in a single casting, the mixture is heated as it passes on to the engine, and condensation is prevented to a certain degree. If the surface of the inlet manifold that is exposed to the heated section of the exhaust manifold is sufficient to heat the mixture at low engine speeds and prevent condensation, this arrangement results in an overheating of the mixture when the engine is running under wide-open throttle conditions. It consequently becomes difficult to design the manifold to provide correct temperatures for all load and climatic conditions.

If the exhaust heat applied to the inlet manifold is controlled by a cut-off so that the heat is reduced when the throttle opening is increased, it should be clear that the temperature resulting cannot be accurate when such an arrangement is used upon two engines under extremely different conditions. Even with this arrangement the air entering the carburetor must still be heated by an air heater, and with one engine operating in the winter months in the temperate zone, and another operating in the summer months in a tropical country, there will be a difference in atmospheric temperature of from 125° to 150° F.

Overheating of the mixture will be the result of such heat application during the summer months in tropical countries when throttle is opened for average running, and too little heat will be applied to the mixture of the engine operating in the northern country during the winter months.

The fuel situation today is a question of proper application of heat. If the mixture is heated sufficiently to prevent condensation of the gasoline in the inlet manifold, a very marked falling off in the power of the engine occurs from the expanding of the gas in the inlet manifold. A compromise must be made between an absolutely dry mixture and a very wet mixture, and with present-day gasoline, a wet mixture must be contended with. If the temperature in the inlet manifold could be maintained near 100°, the mixture, though wet, would give satisfactory results. The temperature within the inlet manifold is frequently so far below the desirable temperature, that the mixture reaches the combustion chamber in a very wet state and destroys the lubricating qualities of the oil on the cylinder walls, and finding its way by the pistons, dilutes the oil in the crankcase. Carbon also forms rapidly in the combustion chamber, for the principal constituent of gasoline is carbon.

In cold climates when an engine is used for short runs, followed by long idleness, as part of a day's duty, the mixture in the inlet manifold may never reach the desired temperature. The grade of fuel used has an important bearing upon temperatures, and unless considerable time is devoted to warming up the engine thoroughly, ordinary gasoline as fuel is likely to result in disaster on the take-off.

In tropical country during the summer months the combined atmospheric temperature, air heater, and hot spot manifold may cause an inlet manifold temperature of several hundred degrees. Yet this would be less harmful than a low temperature. To make a dry mixture in the inlet manifold with ordinary fuel necessitates more heat than most heating arrangements will provide, and where excessive heat application is encountered the drawback will simply be a lack of power and possibly overheating of the engine from the expanded mixture in the inlet manifold.

To compensate for low temperature in the carburetion system there is a tendency toward using the choke to enrich the mixture instead of proper heat application and cowling. When the choke is closed, or partially closed, this amounts to the same thing as changing the adjustment of the carburetor. Restricting the flow of air increases the suction upon the spray nozzle, resulting in a richer mixture.

The choking of the carburetor for starting a cold engine is necessary,

but to take off with the choke partially closed to maintain engine speed is a serious error. The destruction of cylinder-wall lubrication and the dilution of the oil in the crankcase take a toll in prematurely worn-out cylinders, pistons, and crankshaft bearings, not ordinarily realized.

There is a prevailing idea among some mechanics that twice a year the carburetor must be adjusted. It is considered necessary to enrich the mixture slightly when winter approaches, and return to a leaner adjustment in the spring. Many carburetors are not provided with adjustments to control the fuel, and the choke is resorted to for an enriching of the mixture. No change of the mixture should be made at any season of the year except for starting, for the correct adjustment of the carburetor for warm-weather operation will be correct during cold weather, if care is exercised in maintaining the proper operating temperature under the engine cowling and of the water in the radiation system in a water-cooled engine.

It must be understood that choking the carburetor for starting a cold engine is necessary, for the engine demands a rich starting mixture, but it should also be understood that the choke should be adjusted to the open position as soon as possible, and that will be when the engine has become thoroughly heated. If it is necessary to "taxi" into the open immediately after starting the engine, and the outside temperature is cold, the radiator should be protected if possible to bring the operating temperature up to normal as quickly as possible.

When it is necessary to operate an engine with the atmospheric temperature in the neighborhood of zero, it is often possible to fly great distances with the shutters on the radiator closed before the water in the radiator will approach the boiling-point, if the engine was not warmed up thoroughly before leaving the shelter of the hangar. An engine which has not been thoroughly heated will quickly reach a dangerously low temperature when exposed to a cold wind, and great care should be exercised to prevent the engine's stalling on the take-off from a sudden drop in the temperature of the carburetion system.

Those engines provided with a radiator having shutters controlled from the cockpit and a thermometer to indicate the temperature of the cooling system are well equipped for cold climates, and the correct temperature can be maintained by the pilot with little trouble. Too much reliance, however, must not be placed in the correct temperature of the cooling system. Operating the engine at a correct temperature in the cooling system gives the best obtainable thermal efficiency from the engine; yet the carburetion system may still be entirely too cold to provide proper vaporization of the fuel. This condition is seriously

aggravated with low-grade fuels, which demand considerable higher temperatures than aviation fuel requires.

While flying in cold climates, a great deal of thought must be given to correct inlet manifold temperatures, until the time arrives when such engines are equipped with distant type thermometers from the inlet manifold and a manual control of the heat application. Such an arrangement will make it possible for the pilot to maintain correct operating temperatures regardless of flying conditions.

It is of the utmost importance to maintain as near a correct temperature in the carburetion system as is possible, and this may not be maintained if the air heater is not connected with the carburetor and the carburetor is exposed to the open air directly or indirectly. The temperature of the water in the cooling system may be brought to the boiling-point by closing the radiator shutters, yet the temperature in the inlet manifold may be too low to prevent excessive condensation of the fuel. It follows, then, that in order to gain the utmost efficiency, the temperature of the entire carburetion system as well as the cooling system of the engine must be normal. If this is brought about by correct heating of the air taken in by the carburetor or protection for the carburetor as well as proper protection for the radiator, there will be no necessity of changing carburetor adjustments or continuous employment of the choke.

In countries where the winter temperature is frequently far below zero for long periods, special efforts may be required to obtain and maintain correct temperatures under the engine cowling and cooling system. Special cowling may be required which will prevent strong draughts of cold air from reaching the carburetor and induction system. If these precautions are taken to heat the carburetion system sufficiently to prevent condensation, increased life to the engine will result, as well as lowered fuel consumption, though the temperature of the engine cooling system may be below normal at all times.

PRACTICAL TESTS FOR MIXTURE RATIOS

It has been previously pointed out that a rich mixture is required at low engine speeds. The term *rich mixture* may mean a proportion of gasoline and air in which gasoline is in *excess* of the desired amount, or it may refer to a mixture which is purposely *near the limit.* Therefore, when a rich mixture is referred to for a running engine at low speeds, it is not one with an excessive amount of gasoline, but instead is a mixture in which gasoline is near the excessive amount.

A very rich mixture is needed for starting a cold engine because

there is less substance in the gasoline which will vaporize at low temperatures; therefore, more of the liquid fuel is needed. Such a mixture, though rich, is entirely too rich for a running engine after normal operating temperature has been reached.

Though an engine is run at low speeds upon what is termed a *rich mixture,* it must be remembered that to be correct the mixture must be *near the limit,* and, in relation to the mixture demanded by the engine at high speed, it is still a *rich mixture.*

A mixture which is richer than is required to sustain combustion at low or moderate engine speeds will cause an engine to overheat. This is due to the excess of heat units in the combustion chamber causing the mixture to burn slowly. In this case the greatest temperature is reached after the piston has descended well down in the power stroke, with the result that a great area of the cylinder wall is exposed to the heat which is absorbed by the water about the cylinders. The engine may also run irregularly caused by "loading up" of gasoline in the inlet manifold, which is nothing more than a condensation of the gasoline in the inlet manifold due to the excessive richness of the mixture.

If the mixture is extremely rich, heavy clouds of black smoke will be exhausted, accompanied by a strong odor of partially burnt and unburnt gases. Some of this gas accumulating in the exhaust pipe may be ignited by the heat of a stray exhaust flame, causing *after-firing,* commonly but erroneously known as *backfiring.*

The symptoms of an extremely rich mixture are easily recognized, and such a mixture is the *lower limit* of air the engine will run on, and further enriching of the mixture would result in a proportion with insufficient air to form a mixture that would explode at all.

The so-called *rich mixture* for low engine speeds must necessarily have enough air to prevent overheating, after-firing, and emission of black smoke, yet be of a proportion rich enough to sustain combustion.

A lean mixture refers to a proportion of gasoline and air in which air is either in excess of the desired amount or purposely *near the limit.* As in the case of a rich mixture, figures are of little value except to serve as examples, for a proportion of one part of gasoline to seventeen parts of air might be a lean mixture of correct proportions for one engine, yet too lean for another engine which might perform best on a mixture ratio of one to fourteen. The former would be the limit of air for one engine and the latter the limit of air for another engine; yet in respect to each engine they would be lean mixtures.

A mixture may contain so much air that no explosion would result, just as a mixture may become worthless from an insufficient amount of air. To obtain the best economy as much air as is possible must be

used, though it will bring about a slight decrease in power at high speeds. The limit of air is reached when the excess air causes a marked falling off in power.

The decrease in power resulting from the use of a very lean mixture is caused by the lack of heat units in the mixture. With less heat units the temperature during expansion is less, and with this drop in temperature there is a corresponding lowering of expansion pressure, resulting in less force being exerted upon the piston during the power strokes. A further leaning down of the mixture beyond this point brings about explosions through the inlet manifold and carburetor, known as *popping back.* These explosions through the carburetor result from lowered expansion pressure during the power strokes. With a drop in temperature, from the lack of heat units in a lean mixture, there is a drop in expansion, and with a drop in expansion there are insufficient expanding qualities to the exhaust to carry out the heat thoroughly when the exhaust valve opens in the power stroke. This results in a retention of heat in the cylinder, which the exhaust stroke cannot expel in time to prevent ignition of the next incoming charge when the inlet valve opens. The prevailing belief is that *popping back* is due to the lean mixture being so slow burning that the flame is still within the cylinder when the inlet valve opens. If this were true, a rich mixture would also cause a popping back, for a rich mixture is slower burning than the average lean mixture. Yet the excess heat units in a rich mixture provide a high enough temperature to insure sufficient expansion to carry out the heat when the exhaust valve opens in the power stroke. The early opening of the exhaust valve is depended upon to clear the cylinder of the heat, and not the exhaust stroke. The exhaust valve is opened early enough in the power stroke to insure the then existing pressure in the cylinder carrying itself out through the open valve. The exhaust stroke is made use of to clear the cylinder of stray dead gas which might be retained, and the point should not be forgotten that even a 100 per cent cleaning of the cylinder when the exhaust valve opens would not enable one to do away with the exhaust stroke. The exhaust stroke is forced upon the engine builder in a four-stroke cycle engine, for it is necessary to return the piston to upper center again in order to start a new cycle of events.

When the exhaust valve opens in the power stroke, the expanding qualities of combustion of a lean mixture may be so low that the heat is not carried out through the open exhaust valve. This condition leaves the cylinder filled with highly heated air and gas not all of which is expelled by the upward movement of the piston on the exhaust stroke The incoming fresh charge does not require an electric spark to ignite it,

and the highly heated content of the cylinder accomplishes ignition of the fresh charge which is instantly carried back through the inlet manifold and carburetor through the open inlet valve.

The *popping back* through the inlet manifold and carburetor becomes a warning that the *upper limit of air* has been passed. A slightly richer mixture is required to stop the *popping back;* yet this mixture may not give the greatest power and freedom from overheating, although it is the *upper limit of air.* A carburetor so adjusted that the mixture is just rich enough to prevent *popping back* when the throttle is opened gradually will give the greatest economy, but at a sacrifice of power and acceleration, and may lead to overheating.

It follows, then, that a slightly richer mixture will prevent overheating, give the maximum amount of power and acceleration without the popping back, and also be fairly economical. Such a mixture, though slightly richer than the *upper limit,* still remains a lean mixture, for it is *near the upper limit.*

VARIABLES

/In Fig. 51, an addition to the almost complete carburetor is shown, the addition being the *venturi tube.* This is a narrowing of the passage about the spray nozzle. The venturi increases the flow of air through the carburetor by its shape. Above the spray nozzle a vacuum is created which lowers the resistance offered the air flow and allows more air to pass in a given time. The velocity of the air is also greatest at the narrowest point of the tube, causing a concentration of suction upon the spray nozzle. The venturi tube is also known as the *choke;* it should not be confounded with *choking* the air intake of the carburetor for starting a cold engine.

The venturi tube, having a direct control over the amount of air reaching the combustion chamber of the engine, becomes an adjustment when its size is varied, just as a needle valve in the spray nozzle and the changing of the size of a *set jet* are variables. It should be clearly understood, however, that the venturi tube has been selected by the manufacturer after a great deal of experimenting, and it should never be changed for another size unless the peculiarities of the carburetor are intimately known through long experience.

CARBURETOR PECULIARITIES

After carburetion principles have become fixed in the mind, those designs which are of interest should be studied by obtaining an authentic description of the carburetor from the manufacturer or his authorized

agent. It is not possible to have an intimate knowledge of every carburetor that has existed, unless years are devoted to the subject.

Those carburetors which are of general interest and in universal use should be the only ones considered, and each one concentrated upon until it is thoroughly understood. Next to a sample carburetor a good drawing and photographs of the internal parts are of great benefit when accompanied with a printed description of the carburetor's action and its adjustments.

First in interest when examining a strange carburetor is determining what principle is employed to bring about compensation. If an auxiliary air valve is used, some idea is gained as to the principle involved. Yet further examination may disclose that the air valve is used in combination with a metering pin and possibly in conjunction with a dash pot. A too hasty arrival at conclusions as to the purpose of each part may lead to a serious misunderstanding. No other part of an engine demands so much careful thought and reasoning as does the carburetor. That adjustment which may be called a low-speed adjustment on one carburetor may affect other speeds to a greater extent upon one make than upon another. In one description of a carburetor the venturi tube may be referred to as the *choke*, while in another it may be the *strangler tube*. Right-hand threads may be used on an adjustment of one carburetor, but on another they may be found to be left-hand threads.

The plain tube carburetors appear simple, but when their theory is studied it will be found that more imagination is required than with those carburetors having many moving parts.

It is possible to make a carburetor without external adjustments, but it is not satisfactory to do so unless great care is used by the manufacturer in the selection of jets and venturi tube for the particular engine for which the carburetor is intended. Such models must still resort to an idle adjusting screw if satisfactory operation is desired. Idle adjusting screws, also called regulating screws, are found on some carburetors, and, as a regulating screw is used in conjunction with a starting device, the action should be studied. In most cases too much reliance is placed in an *idle adjustment*, for the idle adjustment affects the mixture but slightly except when the throttle is practically closed for idling speeds.

ADJUSTING THE CARBURETOR

Before any carburetor adjustment is changed it should be determined whether there is need for a change. It is a well-known fact in the automotive world that the average person with limited carburetor

knowledge is too eager to experiment with adjustments. Some carburetors require painstaking efforts to find the adjustment that serves best for all conditions, and an unthinking person can quickly undo what has previously taken a great deal of experimenting to secure.

Unless an adjustment is found loose and shows signs of having turned through vibration, it is more likely to be correct than at fault. If the carburetor is suspected because of popping back through the carburetor, the inlet manifold gaskets should be examined for leaks. The additional air drawn through a defective gasket is sufficient to cause a lean mixture. The inlet valves should be inspected for possible sticking when the motor is accelerated, and the valve springs examined for breakage or lost tension. The flow of gasoline to the carburetor may be reduced by a clogged fuel supply line, or water may have found its way into the gasoline. Any of these troubles will cause a popping back, and as it is well known that a lean mixture causes a popping back, many, misguidedly, resort to carburetor adjustments to enrich the mixture.

When heavy clouds of black smoke are emitted from the exhaust accompanied by after-firing in the exhaust pipe, which indicates a rich mixture, it should be noted whether this condition follows immediately after a dying of the engine. Ignition troubles, which cause an occasional "laying off" of the engine, will result in after-firing. Unburnt gas will also be exhausted when the ignition fails now and then from a loose connection or other trouble.

A very lean mixture may also cause after-firing in the exhaust pipe just as a rich mixture may. For example, a leak at a joint in the inlet manifold will cause a lean mixture when the throttle is almost closed, for the vacuum is greater in the manifold with the throttle almost closed. When the throttle is opened, the vacuum in the inlet manifold is not so great, and suction on the faulty gasket is not so strong. It is obvious, then, that the engine may run fairly well when the throttle is open and fail when the throttle is almost closed. If the air leak in the manifold is bad, the entering air may be sufficient to prevent entirely a mixture rich enough to ignite reaching the engine. The lean mixture, failing to burn in the engine, is exhausted into the exhaust pipe, where it accumulates and may be ignited when the throttle is again opened to prevent the engine stopping.

When indications are, however, beyond a reasonable doubt that the carburetor is out of adjustment, the position of the adjustment should be noted so that the original position may be recovered if a change brings about worse results. If the carburetor does not respond to the changes of adjustment in a satisfactory manner, the carburetor

should be removed and carefully cleaned out. The usual routine of cleaning out the jets and passages should be followed as well as an examination of the float made for excessive weight, after which the gasoline level should be checked. The correct height of the gasoline in the spray nozzle is information of great importance on carburetors having no external adjustments, for any change of the level affects the flow of gasoline from the spray nozzle. In some cases the level may be $\frac{1}{64}$ and in other cases as much as $\frac{1}{8}$ in., and if the correct information is not available it is impossible to ascertain the correct level without exhaustive experimenting. When external adjustments are provided on a carburetor, a slight variation in the gasoline level from the correct height can be compensated for by a change of adjustments.

The use of *set jets* in carburetors has removed the necessity of adjustments after the jets have been cleaned out and the carburetor again attached to the engine. The jets are carefully selected at the factory, so that the adjustment will be correct for the engine for which the carburetor is intended, and it should be understood that these jets should not be changed if it is known that they are the original jets and the engine has performed well with them.

To give instructions for adjusting a carburetor fitted with external variable adjustments becomes impossible without the carburetor's peculiarities being known. However, before any adjustments are attempted the engine should be started with the adjustments in a position which allows the engine to run until it is thoroughly warmed up. This is of the greatest importance, for any adjustment made while the engine is cold will usually be entirely too rich after the engine is heated.

ADJUSTING FUEL NEEDLE VALVE

The following instructions relative to the adjustments of fuel needle valves and auxiliary air valves are given as a necessary part in the description of the evolution of carburetors. While fuel needle valves and fuel needle valves combined with auxiliary air valves are not found upon modern designs of carburetors, an understanding of the adjustments of the older types leads to a more perfect understanding of carburetion.

Those carburetors which were provided with a fuel needle valve as the sole means of adjustment may be regulated as follows:

First.—Open needle valve from 1 to $1\frac{1}{2}$ turns.

Second.—Close air passage to obtain a rich mixture for starting, or accomplish this by sinking the float.

Third.—Start engine, and allow it to run until the water in the cooling system is up to normal temperature and the inlet manifold is hot.

Fourth.—Open throttle until engine is running at a fair speed with the spark lever from a quarter to half way toward full advance. The fuel needle valve should then be turned, in the direction that shuts off the fuel, until the engine slows down from the want of gasoline. The needle valve should next be turned in the opposite direction, just enough to recover the engine speed.

Fifth.—With the spark lever from half to three-quarters of the way toward full advance, "flash open" the throttle suddenly, and if popping back occurs the mixture should be made slightly richer at the needle valve.

COMPOUND NOZZLE

In Fig. 54 is shown the well-known principle of the compound nozzle. This type, familiar to all who have come in contact with the

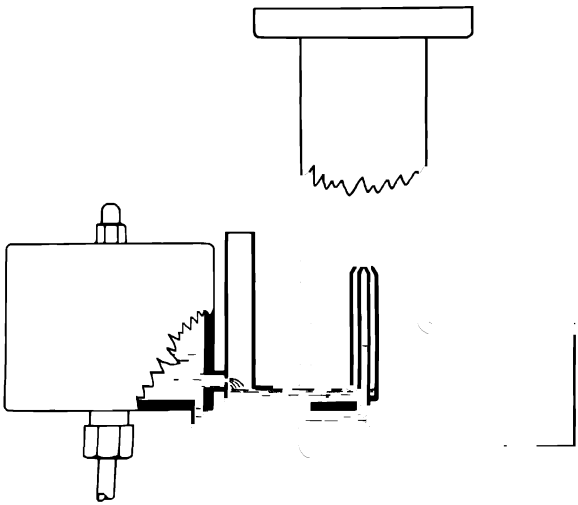


FIG. 54.—The Compound Nozzle Carburetor Principle.

Zenith carburetor, comes close to being without external adjustments, for an idling adjustment is all that is readily variable.

This type of carburetor is fitted with predetermined jets and venturi tube for a particular engine, and it is only through a change of these variables that the mixture can be altered to any considerable degree.

The variables consist of the venturi, the main jet, the compensator, and the idling well. These variables should not be changed without an intimate knowledge of the carburetor and the engine requirements.

The external idling adjustment controls a small air intake at the

top of a starting well. This well also has a small opening into the inlet manifold just above the throttle butterfly valve, from which gasoline is drawn when the throttle is practically closed. This idle adjusting screw controls the mixture at idling speeds, and ceases to function when the throttle is opened and the compound nozzle comes into action.

PLAIN FUEL JET AND AIR BLEED

In Fig. 55 is shown the well-known principle of the plain fuel jet and the air bleed of the Stromberg carburetors. This type of carburetor also has "fixed" high-speed jets, and is equipped with idling adjustments which affect low speeds. The action of carburetors employing the plain fuel jet and air bleed should be studied carefully in order for one to become familiar with the *variables* which constitute the adjustments. See the section on the Stromberg Carburetor further on in this treatise.

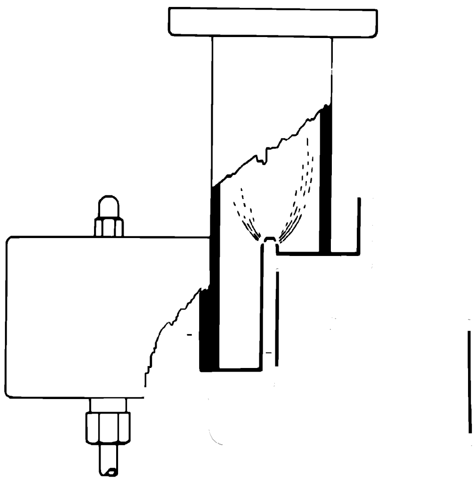


Fig. 55. The Plain Fuel Jet and the Air Bleed Carburetor Principle.

The question of altitude must be taken into consideration when adjusting a carburetor either by external adjustments or by the change of "fixed jets." The greater the altitude above sea-level the less air finds its way through the carburetor, because of the reduced air pressure. Some carburetors are affected more by high altitudes than others, and the same thing may be said of engines. However, most carburetors, if correctly adjusted at sea-level for the maximum amount of air, or the minimum amount of fuel, will not give any serious trouble up to 10,000 feet above sea-level; but a carburetor that is slightly rich at sea-level may cause considerable trouble at very high altitudes. Unless an engine is intended to operate at very high altitudes over a long period after being correctly adjusted at sea-level, the adjustments should not be changed if it is practicable to fly with the adjustments given at the lower altitudes.

Those carburetors which were provided with cockpit control for regulating the gasoline and air were readily altered to suit the conditions, and at such times the controls were a decided advantage when operated by one who thoroughly understood the requirements. Unfortunately, the variation of carburetor mixtures calls for a more intimate knowledge of carburetion than the average pilot may possess, and the variations are best left to automatic means.

The heating of the engine at high altitudes must not be wholly attributed to carburetor adjustment, for, in the case of water-cooled engines, the water boils at a lower temperature as the altitude increases, and no matter what adjustments at low altitudes are made to the carburetor, the engine will develop less power, because of reduced compression brought about by the lower atmospheric pressure.

It is often advantageous to disconnect the hot-air pipe or open the cold-air shutter at the air opening in the carburetor if altitude is attempted where warm air is encountered. This will prevent an over-expansion of the mixture in the inlet manifold and permit a better charge to reach the combustion chamber. It should be understood, however, that this does not apply to extreme altitudes where low temperature will be encountered regardless of ground climatic conditions.

Owing to the fact that some aircraft engines may reach extremely high altitudes, some provision is often made to bring about a leaning down of the mixture, when desired. This has been successfully accomplished by manually controlled *altitude valves*, which, when open, direct inlet manifold vacuum upon the space above the gasoline in the float chamber and thus starve the jets a sufficient amount to decrease the flow of gasoline by opposing the suction on the jet or jets.

SUMMARY OF POINTS ON CARBURETION

Point 1.—Any simple arrangement consisting of an opening for gasoline and an opening for air can be regulated so as to be correct for any engine running at one speed.

Point 2.—When an engine is operating at a correct temperature in the cooling system, it does not follow that there is sufficient heat applied to the carburetion system. Both must be at correct temperature to obtain high efficiency.

Point 3.—The lower the grade of fuel used, the higher its boiling-point, therefore, the more heat necessary to bring about correct vaporization.

Point 4.—A low temperature of the mixture entering the engine results in heavy carbon deposits in the combustion chamber, a thinning

of the oil on the cylinder walls, and a dilution of the oil in the crankcase.

Point 5.—An excessive application of heat expands the gas in the inlet manifold and reduces the power of the engine from a lowering of its volumetric efficiency.

Point 6.—Closing the air inlet of the carburetor by use of the choke amounts to the same thing as changing the carburetor adjustments. Continued running of the engine with the choke partly closed is dangerous to the life of the engine unless the oil in the crankcase is changed frequently.

Point 7.—No carburetor adjustment should be changed until it is certain beyond a reasonable doubt that the carburetor is at fault. If winter conditions prevail, an increase in the applied heat to the carburetion system and a maintaining of correct temperature of the water in the cooling system will permit the engine to run efficiently with the same carburetor adjustment as was used during the summer months.

Point 8.—The peculiarities of different carburetors should be studied, and all the available information should be sought and kept for reference, so that the principle of their adjustments will be clear in the mind. When one feels his education on carburetors is above the average, the slogan: *Keep the temperature right and leave the adjustments alone,* is more likely to be adopted than the practice of "tinkering."

CHAPTER VII

AIRCRAFT ENGINE CARBURETORS *

The carburetion theory previously given in this text is well exemplified in the Stromberg carburetors. The Stromberg Motor Devices Company manufactures a series of standard single-barrel carburetors, particularly adapted to the requirements of air-cooled engines, and also double-barrel and triple-barrel models, each designed especially to fit one or two types of engines.

Owing to the number of different models, it is not practicable to cover in this treatise a detailed description of each one; but, as these models are all substantially similar in principle, and the construction of representative types is described, the information furnished will be found generally applicable. Detailed instructions as to proper jet sizes, fuel level settings, etc., will be found in the instruction books of the engines upon which each of these carburetors is used.

MODEL DESIGNATION

All Stromberg Aircraft Carburetors carry the general model designation NA. Following a hyphen (-), the next letter indicates the type, as shown by the following table:

Type Letter	Type Description
S	Single-barrel (old series)
R	Single-barrel (new series)
D	Double-barrel, float chamber to rear (obsolescent)
U	Double-barrel, float chamber between barrels
Y	Double-barrel, double float chamber fore and aft of barrels
T	Triple-barrel, double float chamber fore and aft of barrels

The final numeral indicates the nominal rated size of the carburetor, the sizes starting from 1 in., which is No. 1, and increasing in $\frac{1}{4}$-in. steps. For example a 2-in. carburetor is No. 5. The actual diameter of the

* The data in this section are presented through the courtesy of Stromberg Motor Devices Co.

carburetor barrel opening is $\frac{3}{16}$ in. greater than the nominal rated size, in accordance with the standards of the Society of Automotive Engineers. A final letter is often used to designate a special series of one particular model. The model designation and serial number will be found on an aluminum tag riveted to the carburetor.

Single-Barrel Carburetors.—There are two series of single-barrel carburetors in use at the present time, the older of these designated by the type letter S and the new series by the letter R. Many models of the S series are now obsolete. The NA-S5A, NA-S5B and the NA-S12 are, however, still in general use. The NA-S5A and NA-S5B have a hinge-type float mechanism, the accelerating well type of main discharge nozzle assembly, and the back suction type of mixture control. The design does not include an accelerating pump or an economizer. The NA-S12 is a single-barrel type with a double float chamber designed for use on the Packard 800 h.p. engine, Model 3A-2500. Additional information concerning the S series carburetors may be obtained from Edition 2 of the Stromberg Aircraft Carburetor Manual.

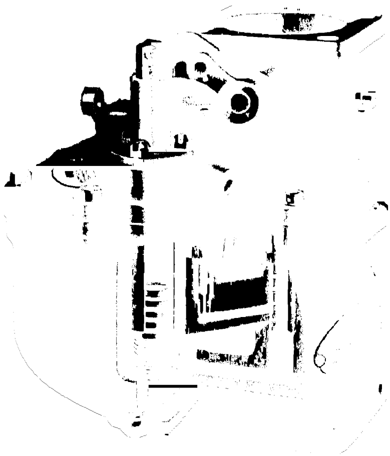


FIG. 56.—The NA-R5A Stromberg Carburetor.

The R series of vertical single-barrel carburetors consists of the following models:

SIZE	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3
MODELS	NA-R3 NA-R3A	NA-R4 NA-R4A	NA-R5 NA-R5A NA-R5C	NA-R6	NA-R7	NA-R9

These models have been designed to meet the requirements of air-cooled aircraft engines of all types and sizes, ranging from 50 to 400 h.p. They are quite similar in general design and construction, differing only as regards details. A hinge type of float mechanism, located in a float chamber at one side of the barrel, is used. All models are fitted with a needle valve type of mixture control, an accelerating pump and an economizer.

The main body is interchangeable on the four models of the $1\frac{1}{2}$-in. and $1\frac{3}{4}$-in. carburetors. The throttle shaft on the NA-R3 and NA-R4 is perpendicular to the center line of the float chamber, and on the NA-R3A and NA-R4A it is parallel to the center line. On early models the float fulcrum, fuel inlet and strainer were incorporated in the throttle valve body, but on later models these are incorporated in the main body.

The accelerating pump and economizer are combined into one unit in these models. A primer and warming-up control is sometimes provided.

The main body is interchangeable on all models of the 2-in. and $2\frac{1}{4}$-in. carburetors. The float mechanism and float chamber is larger than that on the $1\frac{1}{2}$-in. and $1\frac{3}{4}$-in. models, and the main discharge nozzle boss is vertical, whereas on the smaller sizes it is inclined. A poppet valve type of economizer, operated by the accelerating pump stem, is used.

FIG. 57.—The NA-R9 Stromberg Carburetor.

The NA-R7 and NA-R9 models are quite similar in design, with many parts interchangeable. Although the floats are the same, the float chamber on the NA-R9 is larger than that of the NA-R7. A needle valve type of mixture control and economizer is used.

Double-Barrel Carburetors.—The double-barrel models include the following types: the D series, having the two barrels together with the float chamber to the rear, the U series in which the float chamber is located between the barrels, and the Y series which have two floats and float chambers located fore and aft of the two barrels.

D Series.—All models of the D series are obsolescent at the present time. These were used on the Hispano-Suiza engines, Models A, E, and H.

U Series.—In the U-type carburetor a single float and float chamber are provided between the two barrels of the carburetor. With this design the over-all width of the carburetor is necessarily greater than that of the Y or other types.

The NA-U4J model has a jacketed throttle valve body designed for

use with an exhaust jacketed manifold or elbow. The inlet to the carburetor jacket is located in the flange so that a connection may be obtained without external piping. A flanged outlet connection is provided at the rear of the carburetor. An air intake elbow is incorporated in the design of the main body so the air-intake flange is in a vertical plane. The mixture control is of the back suction type. The accelerating charge is obtained from the accelerating well type of main metering system.

The NA-U6T and the NA-U6TB are of similar design and are suitable for use in the V of a large V-type engine. The accelerating well type of main discharge nozzle and the back suction type of mixture control are used. The throttle valves of the NA-U6T are mounted on the same shaft, whereas two parallel shafts operated by gear segments are used in the NA-U6TB.

FIG 58—The NA-Y7B Stromberg Carburetor.

The NA-U8J has a jacketed throttle valve body similar to that used on the NA-U4J. The accelerating well type of main discharge nozzle and the back suction type of mixture control are used in this design. In addition to the standard accelerating well a combination economizer and accelerating pump is used. This carburetor in its present form is suitable for use only in connection with a supercharger, with the induction system so arranged that the mixture from each barrel enters a single passage leading to the supercharger entrance.

The NA-U10J is designed for use on engines of approximately 600 h.p., fitted with a supercharger having sufficient capacity to maintain sea-level density in the manifold at 10,000 to 15,000 feet altitude. Under these conditions the carburetor must be operated at part throttle on or near the ground. This model has a jacketed throttle valve body similar to the design used on the NA-U4J.

Y Series.—The Y type of carburetor has two float chambers, one

at the front and one to the rear of the two barrels. A float is used in each of these float chambers, but these are connected by means of a float bracket which operates one needle valve. With this design, if the position of the airplane is changed, as from level flight to a climb or dive, the fuel level is raised in one float chamber and lowered in the other, but the level at the discharge nozzles, located between these float chambers, is not affected.

The NA-Y5F carburetor was designed especially for use on the Curtiss D-12 engine, two carburetors being installed in the V of the engine so that each barrel of the carburetor supplies three cylinders. The throttles are fitted to parallel throttle shafts connected by gear sectors. The accelerating well type of main discharge nozzle, and the back suction type of mixture control are used. Owing to the lack of space in the V of the engine no strainer is provided in the carburetor. Fuel lines without rubber hose connections are used to connect a fuel strainer, mounted at the rear of the engine, with the carburetors. In order to reduce the width of the carburetor to a minimum, a special form of idle adjustment is used, although the discharge nozzle design is the same as that used on other models.

The NA-Y5D carburetor is quite similar in construction to the NA-Y5F and was designed for use on the same engine. This model is provided with packing glands on the throttle shafts, mixture control stem and idle adjustments so that it may be used on the pressure side of a supercharger. These carburetors are tested under 10 lb. per square inch pressure before leaving the factory to make sure there are no leaks in the air intake or at any of the fittings.

The NA-Y60 carburetor has a barrel diameter of $2\frac{9}{16}$ in., which is $\frac{1}{8}$ in. larger than the standard No. 6 carburetor. This carburetor was designed especially for use on the Curtiss Conqueror Engine, the design and the installation being quite similar to that of the NA-Y5F and NA-Y5D carburetors. Packing glands are used on this carburetor so that it may be used with a supercharger, if desired. The float needle valve seat is provided with a ball check valve, which reduces the quantity of fuel supplied when the carburetor is in an upside-down position. This arrangement permits an unrestricted flow to the float needle valve during normal operations. During any maneuvers in which the pilot tends to leave the seat, or in upside-down flying, the ball valve closes the main opening of the needle valve seat. The fuel supplied to the carburetor under these conditions passes through several small bypass holes which have an area sufficient to supply the engine with the correct mixture, provided the fuel pressure is maintained at approximately 3 lb. per square inch. No economizer is required in this carburetor,

owing to the fact that as installed on the engine each barrel feeds three cylinders only and the pulsations in the air stream at full throttle cause an enrichment of the mixture sufficient to give maximum power.

The NA-Y7A carburetor was designed for use on air-cooled radial engines, such as the Pratt & Whitney Wasp and Hornet, and the Wright Cyclone. The float mechanism on this is practically the same as that on the other Y type carburetors. The accelerating well type of main discharge nozzle assembly is used, and the carburetor is fitted with the back suction type of mixture control. A combined economizer and accelerating pump is incorporated in the design. As installed on the engines mentioned, the mixture from each barrel enters the same passage leading to a low-pressure supercharger, which increases the pressure of the air and fuel mixture, and distributes it to the nine cylinders of the engine.

The NA-Y7B is a modified form of the NA-Y7A carburetor, the difference being entirely in the economizer and accelerating system. The lower piston of the economizer in the NA-Y7B is larger than that of the NA-Y7A, and is fitted with a check valve. This increase in piston size provides a greater accelerating charge, and the check valve prevents a discharge of fuel out of the economizer discharge nozzle when the throttle is quickly closed. The economizer discharge nozzle is also of a slightly different design, which insures all of the accelerating fuel entering the air stream in the venturi.

The Triple-Barrel.—The NA-T4B carburetor, as used on the Wright J-5 Engine, is a triple-barrel carburetor designed especially for use on nine-cylinder radial engines, in which the induction system is so arranged that each barrel of the carburetor supplies three cylinders. The float mechanism used is similar to that of the Y type, a float and float chamber being provided both at the front and at the rear of the carburetor. This carburetor is provided with a back suction type of mixture control and standard three-piece main discharge jet and accelerating well. The three throttles are mounted in one shaft. No economizer or accelerating pump is provided in this model.

BASIC PRINCIPLES OF STROMBERG CARBURETORS

The Plain Jet and the Air Bleed.—It is generally believed that a simple plain fuel jet in a carburetor air opening of fixed size tends to deliver a continuously richer mixture as the engine suction and air flow increase, but this is not accurately true. Under the suctions of medium and high engine speeds, as carburetors are now built, a plain jet will give a fairly uniform mixture; but coming down to low speeds and

suctions, the jet delivery falls off very markedly in relation to the air flow. This is due to the fact that some of the suction force is consumed in raising the fuel from the float level to the jet outlet (to avoid overflow with motor not running, the jet must necessarily stand a safe distance above the fuel level), and in overcoming the tendency of the fuel to adhere to the jet tip. At low suctions, the discharge from a plain jet is as shown in Fig. 59, with the fuel clinging to the metal of the jet and tearing off intermittently in large drops. The discharge from a plain fuel jet is, therefore, retarded by an almost constant force, which is insignificant at high suctions, but which perceptibly reduces the flow at low suctions.

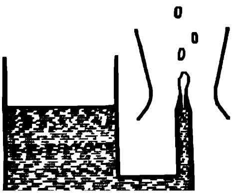


Fig. 59.

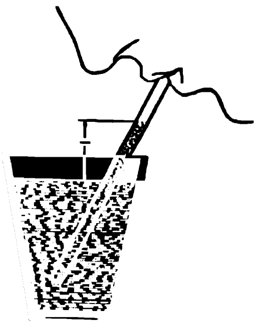


Fig. 60.

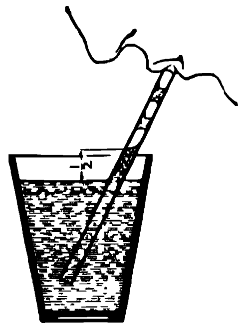


Fig. 61.

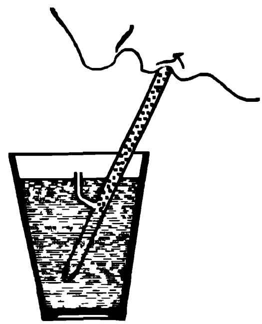


Fig. 62.

The application of the "air-bleed" principle in overcoming this difficulty is shown in the accompanying illustrations. Fig. 60 shows a familiar instance of how suction may be great enough to lift a liquid above its level, without drawing any of it away. Now if a tiny hole be pricked in the side of the straw above the liquid surface and the same suction applied as before, bubbles of air will enter the straw and the liquid will be drawn up in a continuous series of small slugs or drops, as shown in Fig. 61.

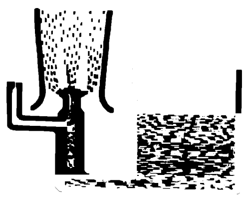


Fig. 63.

Such a construction is not quite suitable for a carburetor jet, as there is still a distance through which the liquid must be lifted from its level before the air begins to pick it up; also the free opening of the straw at its bottom prevents very great suction being exerted on the air bleed hole or vent, just

as too large an air opening in proportion to the straw size would reduce the suction available to lift the liquid. A modification to take care of these points is shown in Fig. 62, in which the air is taken in slightly below the liquid level and a restricting orifice placed at the bottom, with the result that a finely divided emulsion of air and liquid is formed in the tube.

The construction just described, when incorporated into a carburetor jet, takes the form shown in Fig. 63. Such a jet tends to give a substantially uniform mixture under steady speed throughout its range of operation. The mixture proportion can also be modified for high speed and low speed as desired by the proper selection of the dimensions of the air bleed and emulsion channels.

The Venturi Tube.—It is a fortunate and useful result of natural laws that both the air flow through an opening of fixed size and the fuel flow through an "air bled jet" system respond in substantially equal proportion to changes of suction (within the range of air velocities used in the carburetor). To maintain an approximately uniform mixture proportion throughout the power range of engine operation, it is only necessary that the "air bled jet" and metering air opening be exposed to the engine suction in the same degree, which condition is obtained by locating the fuel jet outlet in the center of a definitely formed air nozzle or venturi tube (sometimes called the "choke"), as shown in Fig. 63, both being on the atmospheric side of the throttle valve.

The venturi tube has another use than this, however. Full power output from the engine requires that the manifold suction or partial vacuum above the throttle be between 0.4 and 0.8 lb., at full engine speed, when the suction below the throttle valve is the maximum. From the standpoint of metering and spraying the fuel, it would be desirable to use a suction several times this. It has been found that both these requirements can be complied with by the use of the peculiarly shaped air passage of a venturi tube, consisting of a reduced or constricted central portion with a smooth round entrance and a gradually tapered outlet. With this it is possible to obtain, on a jet located in the central portion, several times the suction existing in the intake passage beyond the venturi tube, and thereby maintain a low manifold vacuum with a high fuel metering suction.

As the venturi tube constitutes the limitation of air capacity of the carburetor, it is made in different sizes which may be selected according to the requirements of the engine to which the carburetor is fitted. The size is usually selected such that, at normal full speed and load, there will be a mean air velocity (during the suction stroke) of 300 ft. per second through the throat or narrowest part. This air velocity should

correspond to a mean partial vacuum at the mouth of the carburetor, with throttle full open, of about 16 in. water during the suction stroke with the carburetor supplying four or more cylinders, 12 in. when supplying three cylinders, and 4 in. when supplying one cylinder.

The Idling System.—The structure of Fig. 63 does not entirely meet the requirements of carburetor service, because at low engine speeds the air flow does not have sufficient force to carry the fuel from the jet to the throttle valve. As shown in Fig. 64, a bypass or idling passage is provided to carry the fuel up to the throttle valve and intake manifold when the main jet suction is weak. This bypass system is practically independent of the main jet metering system and controls the fuel metering only at low engine speeds when the main jet suction is low. As this suction increases fuel will begin to deliver from the main system and the delivery from the idling system will decrease.

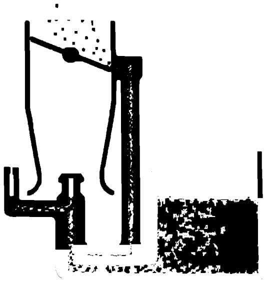


Fig. 64.

The Accelerating System.—It will be obvious that quick changes of engine speed and throttle position would involve rapid reversals of fuel flow through this idling system, tending toward temporary periods of lean mixture. It has been found that these may be avoided by the use of an "accelerating well" (see Fig. 65), which is merely a downward extension or enlargement of the air bleed passage. The depression or suction in the central channel is always greater than in the outer "well" chamber, and any increase in suction on the main jet results in a lowering of the level in the well chamber. The volume of fuel thus displaced temporarily supplements the fuel delivered through the metering orifice, covering up any lag in either the idling tube or main jet passages, and gives a rich mixture when the throttle is opened quickly from low speeds. On engines with long manifold passages operating under cold-weather conditions, greater quantities of fuel than that supplied by the accelerating well around the main discharge nozzle is required, and a pump operated by the throttle is used. This pump, as shown by Fig. 66, is located in the float chamber. As the throttle is opened the sleeve is depressed, forcing fuel through the connecting passage, and out the main discharge jet. A restriction in the connecting passage limits the quantity of accelerating charge pumped.

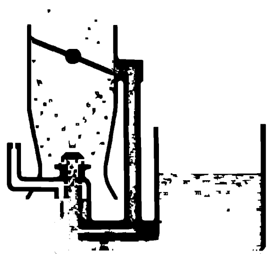


Fig. 65.

The Economizer System.—It is desirable to have a lean mixture for maximum economy at part throttle or cruising speeds, and a much richer mixture for maximum power and the cooling effect on air-cooled engines at full throttle. In order to obtain this change in mixture ratio as the throttle is opened, various forms of economizer systems are used. These in their present form are in reality enrichening devices.

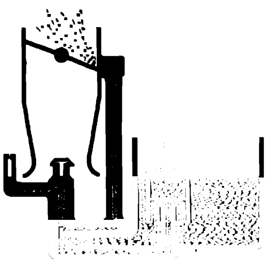


FIG. 66.

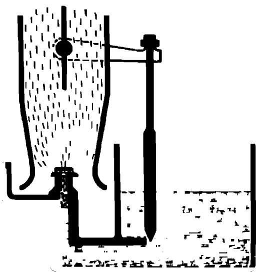


FIG. 67.

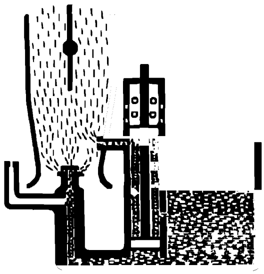


FIG. 68.

The arrangement shown in Fig. 67 consists of a needle valve, which is opened by the throttle at a predetermined throttle position, and permits a quantity of fuel, in addition to that furnished by the main metering system, to mix with the air in the carburetor. Fig. 68 shows a piston-type economizer also operated by the throttle. The lower piston acts as a fuel valve, preventing any flow of fuel through the system at

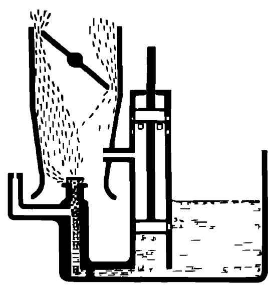


FIG. 69.

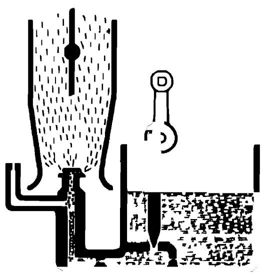


FIG. 70.

cruising speeds, while the upper piston acts as an air valve, and permits air to flow through the separate economizer discharge nozzle at part throttle. As the throttle is opened, the lower piston uncovers the fuel port, so that fuel is drawn through the system and out the discharge nozzle, and the upper piston cuts off the air bleed to the economizer nozzle, thus increasing the suction on the fuel jet. Fig. 69 shows the position of the pistons of the same system at cruising speeds.

Mixture Control.—As the airplane ascends in altitude, the atmosphere decreases in pressure, temperature, and density. The weight of the air charge taken into the engine decreases with the decrease in air density, cutting down the power in about the same percentage. In addition, the mixture proportion delivered by the carburetor is affected, the mixture becoming richer at a rate inversely proportional to the square root of change in air density.

In order to compensate for this change in mixture, a manually operated mixture control is provided on all Stromberg Aircraft Carburetors. The mixture supplied by a carburetor may be made leaner, by reducing the effective suction on the metering system, or by admitting additional air into the induction system through an auxiliary air entrance. Each one of these methods has been used in Stromberg Aircraft Carburetors.

INSTALLATION

There are many factors affecting satisfactory carburetor operation in service which cannot be cared for in carburetor design alone. The requirements regarding tanks, fuel lines, fuel pressure at the carburetor, controls, the application of heat to the induction system, and the effect of rapid acceleration in maneuvers and catapulting must be recognized if the carburetor is to function successfully in the airplane.

Fuel Tanks and Lines.—The tanks and fuel lines must be so located that there is no tendency for an air lock to form in the lines and obstruct the fuel flow. The forces due to rapid accelerations in maneuvers and in catapulting are often greater than the force of gravity, with the result that the fuel shifts in the carburetor and tanks with consequent changes in fuel level. The carburetors are so designed that, with these changes in level, fuel will always flow to the metering system. The flow of fuel to the carburetor must also continue at a normal rate if it is to continue to function. The location of the tanks and their fuel outlets should, therefore, be so related to the carburetor that no interruption of fuel supply takes place under these conditions.

Fuel Pressure.—The fuel pressure at the carburetor should be sufficient to maintain a normal level of fuel in the float chamber of the carburetor. On some of the models the space limitations were such that small float mechanisms had to be used, and on these a pressure fuel system must be used. A fuel pump is generally used with these carburetors, and a fuel pressure of 3 lb. per square inch at the carburetor inlet is recommended. This corresponds to a head of 117 in. of gasoline at .710 specific gravity. Other models, including all the NA-R series, may be used with a gravity system, and a minimum fuel head of 24 in.

is recommended. Under certain special conditions a lower head may be used, but this point should be taken up with the Stromberg Motor Devices Company before an installation is made.

Carburetor Mounting.—The carburetor should always be so mounted on the engine that the fuel level at the discharge nozzle will not be changed during a climb or dive. On the single-barrel models this requirement is fulfilled if the carburetor is mounted with the float chamber at the side. The NA-Y models should be mounted with the float chamber fore and aft of the barrels, and the NA-U models with the barrels at the sides of the float chamber.

Heat Application.—The vaporization of fuel in the carburetor barrel and in the manifold above the carburetor is accomplished through the flow of heat from the surrounding metal into the fuel. Unless heat is supplied to the manifold or the entering air the temperature will drop to a very low value and will interfere with vaporization, and under certain atmospheric conditions will cause a formation of ice in the induction system.

This ice formation constitutes a serious danger and may be sufficient to cause loss in power and rough running of the engine. The manifold immediately above the carburetor should therefore be heated with water, oil, or exhaust gas. Practically the same results may be obtained, although the temperatures must be higher, by heating the inlet air passing to the carburetor.

Controls.—The control rods and levers used to operate the throttle and mixture control should be of rugged construction so that positive operation may be obtained. The use of flimsy wire controls is not recommended. The system should be so designed and built that full movement of the carburetor control levers is obtained, and that the movement is in the proper direction.

Starting.—The best procedure to follow in starting depends to a great extent upon the starter and primer equipment furnished by the engine manufacturer, and so it is impossible to give detailed rules for starting. The following comments concerning the functioning of the carburetor during the starting process should, however, facilitate starting an engine for the first time, or until its starting characteristics are determined.

In turning the propeller either by hand or by a starter, the suction produced at the carburetor is relatively low, and the throttle should be closed, or nearly closed, in order to draw fuel through the idle system into the manifold. The idle wells in the carburetor are of the self-priming type, which is of special value when starting by hand. When the propeller is turned with throttle closed, fuel is drawn from the idle

well through the idle tube and out the idle discharge nozzle. When the operator stops turning to obtain another grip on the propeller this well fills with fuel, so that on the next turn additional fuel is drawn in. Continuous turning of the propeller does not give this action, as the well is soon emptied and air is drawn into the idle tube through the idle air bleed. This priming action is sufficient for warm-weather starting, but as a rule does not provide sufficient fuel for cold-weather conditions, and the primer system on the engine should be used. If no primer is provided the engine may be primed by squirting gasoline into the exhaust ports near the exhaust valve, and then turning the propeller over in the backward direction.

After fuel has been drawn into the manifold or the primer used, the ignition should be turned on and the propeller turned by hand or by the starter, or the booster magneto used, if one is provided. As soon as the engine starts, the throttle should be opened slightly and the engine warmed up at a speed of 700 to 900 r.p.m. On the NA-R carburetors, which are provided with an accelerating pump, the engine can be kept running by partly opening and closing the throttle quickly. This action will operate the pump and supply a rich mixture to the engine.

With a hot engine, or in very warm weather, there is a possibility of getting too much fuel in the induction system. This "loaded up" condition may be overcome by turning the engine backward, or by opening the throttle to the wide open position and turning the propeller forward, thus drawing air with practically no fuel into the induction system.

Adjustments.—The metering jets controlling the fuel flow at full throttle and at cruising speeds are of the fixed orifice type and no adjustment is required. After the engine has been thoroughly warmed up, the minimum speed operation should be made satisfactory by the regulation of the idle adjustment and the throttle stop screw. The operation at idling speed will generally be found to be best with an idle mixture amply rich. It should not be set rich enough to cause the engine to "load up" when idled for a long period of time. After making an idle adjustment the throttle should be opened and then closed quickly to make sure there is no tendency to stop. If there is, the throttle stop should be set to give a faster idle speed. The operation of the engine at all speeds, the acceleration, and the operation of the mixture control should also be checked.

Inspection in Airplane.—The carburetor strainer should be removed and cleaned frequently and the strainer chamber flushed out with gasoline to remove any foreign matter or water. The fuel lines should be inspected to make sure they are tight and in good condition. The car-

buretor should be inspected to make certain that all safety wires, cotter pins, etc., are in place, and that all parts are tight. On those models having economizer or accelerating pumps, the operating mechanism should be frequently cleaned and a small quantity of oil put on the moving parts.

INSPECTION AND OVERHAUL

Disassembly.—The carburetor should be disassembled for cleaning and inspection each time the engine is given a general overhaul, when there has been an accident which might have damaged the carburetor or when its action is known to be unsatisfactory.

In disassembling, the halves should be separated and sufficient parts removed to permit a very thorough cleaning and inspection of all parts and passages. In general this will include the removal of the float mechanism, float needle valve seat, strainer, main discharge nozzle assembly, metering jets, economizer, accelerating pump, mixture control valve, and such passage plugs as are required to clean the passages.

Tapping the brass plugs lightly with a soft wood or rawhide mallet will aid greatly in their removal from the aluminum body. If the threads stick, apply oil and work the plug in and out as is sometimes done in a tapping operation. This will allow their removal without tearing the threads in the aluminum.

Wash all parts and the aluminum castings with gasoline, and clean all passages by blowing through them with an air hose.

Inspection.—The parts removed should all be inspected carefully for wear or irregularities of any kind. Note the condition of the float needle valve and needle valve seat. If the needle is grooved or the sides of the needle valve or needle valve guide are worn excessively, both needle valve and seat should be replaced with new parts. See that the adjustable idle discharge nozzles are clean and that they can be freely adjusted. Check the fit of the throttle valves in the barrel and the fit of the throttle shaft in its bushings. On the double- or triple-barrel models see that all of the throttles close tightly with the throttle stop unscrewed. An adjustment is provided for synchronizing the throttles on double-barrel models having parallel throttle shafts connected with gear sectors. One of the gear sectors is not pinned to the shaft but is clamped directly to it by means of a bolt and nut. Loosening this nut will allow the gear sector to be turned on the shaft and an adjustment secured. On later models of this type, the gear sector, which is not pinned, is fitted over an eccentric bushing. This eccentric bushing may be rotated to eliminate excess backlash between the gear sectors. With this type of adjustment the gears should be set with practically no back-

lash when the throttles are closed. The backlash which will then exist at wide open throttle has no effect on the operation. Examine all passages to see that they are clean.

Assembly.—Reassemble the parts in the lower half or main body of the carburetor, using new parts where necessary. It is very important that all gaskets be in good condition and be properly placed.

Brass plugs screwed into aluminum have a tendency to stick after a long period of service, but this trouble can be obviated by the application of a thin coating of a mixture of powdered graphite and castor oil to these threads.

The needle valve and seat should be checked for leakage by holding the needle valve with the point up and the seat in place, and filling the small space above the needle with gasoline. If any leakage is evident the needle valve should be lapped in with crocus powder. If the leakage cannot be stopped in this way a new needle and seat should be used.

After assembling the lower half of the carburetor move the float up and down to see that it works freely, and inspect it to see that it does not strike the sides of the float chamber. Check the float level by holding the lower half in a level position either on the bench or in a vise and connecting the fuel inlet to a fuel supply tank. Measure the distance from the level in the float chamber to the parting surface. This measurement should check with that given in the detail instructions on the model being tested. In case this information is not available the level should be set $\frac{1}{8}$ to $\frac{3}{16}$ in. below the bottom of the main discharge nozzle holes.

The fuel used and the height of the fuel supply tank above the carburetor fuel inlet should correspond to the conditions actually encountered in service. If the carburetor is used on an airplane having a gravity fuel system, the float level should be set with a fuel head equal to the average height of the fuel in the tanks of the airplane above the carburetor inlet. If used with a pressure fuel system, a pressure of 3 lb. per square inch, or 117 in. of fuel at .710 specific gravity, should be used. In case the level is not correct, adjustment should be made by changing the thickness of the gaskets under the float needle valve seat. In general, a change of $\frac{1}{64}$ in. in gasket thickness will cause a change of $\frac{5}{64}$ in. in the level. In order to lower the level it is necessary to reduce the gasket thickness on some carburetors and increase it on others, depending on the location of the needle valve above or below the float bracket, and on the location of the pivot between the float and needle valve or at one end of the float bracket. Whether to add or remove gaskets is easily determined, however, by an examination of the float mechanism construction.

The setting in the carburetor should correspond to the setting shown on the aluminum tag riveted to the casting unless there is a definitely known reason why it should be otherwise. The individual instruction sheets, usually supplied in the engine instruction book, should be consulted for detailed information concerning each individual model.

Assemble the main and throttle valve bodies and safety wire all screws, plugs, etc.

TABLE OF THREAD STANDARDS USED IN STROMBERG AIRCRAFT CARBURETORS

U. S. Standard Thread Form

No. 8-32*	$\frac{1}{4}$ in.-20*	$\frac{3}{8}$ in.-24*	$\frac{11}{16}$ in.-24
No. 10-24*	$\frac{1}{4}$ in.-24	$\frac{7}{16}$ in.-24	$\frac{3}{4}$ in.-20*
	$\frac{1}{4}$ in.-32	$\frac{1}{2}$ in.-24	$\frac{7}{8}$ in.-24
	$\frac{5}{16}$ in.-18*	$\frac{9}{16}$ in. 24*	$1\frac{1}{2}$ in.-18*
	$\frac{5}{16}$ in.-24*	$\frac{5}{8}$ in.-24*	

* S A.E Standard.

CHAPTER VIII

SUPERCHARGERS *

The addition of a supercharger to a standard aircraft engine to prevent a diminution of power output as the altitude is increased has passed the experimental stage, and to such an extent that superchargers, no longer an exterior accessory, are being built into the engine. On radial engines the shape of the crankcase simplifies making the supercharger an integral part of the engine. The rear portions of the crankcase and central casting of the radial engine are designed so that this section of the engine forms the parts of the casing of the centrifugal supercharger.

Before the supercharger had been developed to its present stage, it seemed that no further reduction in the weight-horsepower ratio of aircraft engines was possible. As the efficiency of an engine depends to a great extent upon its compression, the reduction of compression as the engine reached any altitude above sea-level was a serious obstacle which the supercharger has minimized.

It is not at all sufficient for an engine to give satisfactory performance at sea-level or up to five thousand feet, for in military work and for commercial purposes it becomes highly desirable for an engine to maintain sea-level power, or approximately sea-level power, up to fifteen thousand feet.

The superchargers of the General Electric Company are widely used for military and commercial work, and the following description serves as an example of supercharging principles and application.

The General Electric Company supercharger consists of a high-speed impeller driven off the engine shaft through a train of gears. The gearing used to drive the magnetos, oil pump, generator, starter, etc., is arranged to provide a drive for the impeller. Surrounding the impeller, air conduits are arranged having the proper shape, and as these conduits are part of the engine crankcase, the embodying of a supercharger within the engine becomes a matter of a small impeller and a few additional gears.

* This chapter was arranged from information kindly furnished by the General Electric Company.

The impeller rotates at a speed from five to fourteen times the crankshaft speed, according to the engine service requirements and the gear ratio adopted to meet these requirements. Located between the carburetor and the combustion chambers of the engine, the high-speed impeller compresses the fuel and air drawn through the carburetor before it enters the cylinders of the engine. Placing the impeller between the carburetor and the cylinders of the engine creates a more complete vaporization of the gasoline than is otherwise possible while maintaining

Fig. 71. The Curtiss Chieftain with Built-in G-E Geared Supercharger.

a single-barrel carburetor, regardless of the number of cylinders in the engine. In fact, this improved vaporization has been in some cases sufficient reason for use of the General Electric system, independent of the matter of increased power.

The supercharger design for which the General Electric Company takes responsibility includes the layout of the passage between the carburetor and the inlet to the impeller, the arrangement of the casing surrounding the impeller, the layout of the diffuser, which is a chamber immediately succeeding the impeller, and finally the layout of the pas-

sages conducting the charge from the diffuser to the various cylinders. The diffuser is an important part of the supercharging system. The charge of gasoline and air leaving the impeller is moving at a high velocity and at a certain pressure, because of the centrifugal effect along the centrifugal impeller. The velocity represents a certain amount of energy which has been put into the air, but which is of no immediate use. The diffuser furnishes a properly shaped passage wherein this velocity is gradually decreased with such efficiency that the energy is converted into energy represented by pressure. At the end of the diffuser and the beginning of the passages which distribute air to the engine, there is, therefore, a pressure appreciably greater than pressure at the

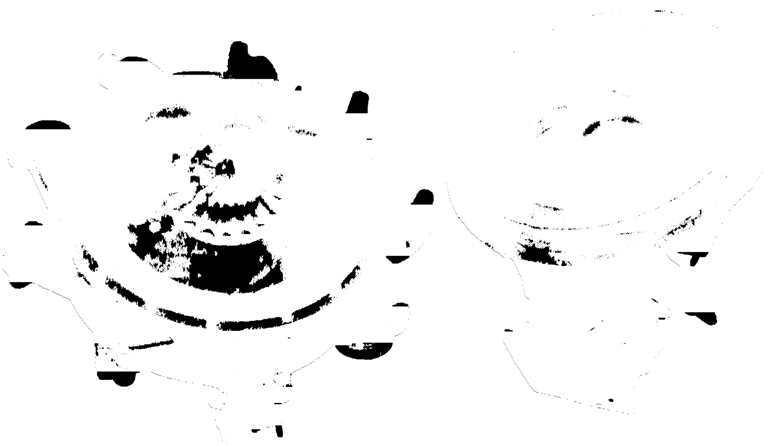


FIG. 72.—Exposed View of the G-E Supercharger on the Hornet.

end of the impeller, and a comparatively low velocity suited to the flow in the pipes from the diffuser to the engine inlet valves. The diffuser also exercises an important function in the vaporization of the gasoline. In order that the diffuser may function properly, the air is necessarily guided through it in curved paths with gradual decrease in velocity. The gasoline drops which leave each of the impeller blades on their forward edges are impelled through the air passing through the diffuser with constant velocity and in straight lines. The arrangement is such that the gasoline drops are continually meeting new air, so that complete vaporization is secured by the time the end of the diffuser is reached. The compression of the air by the centrifugal supercharger creates a slight temperature rise, and this also gives a slight assistance in the

vaporization. However, with ordinary amounts of supercharging, the temperature rise is not such as to give appreciable decrease in the weight of the charge entering the cylinders. The vaporization system mentioned is sufficient without the addition of hot spots or heat of any kind during moderate weather. During cold-weather operation it becomes necessary to add some method of heat application. This is for the purpose of avoiding clogging of the carburetor through ice forming, caused by the vaporization of the gasoline, and also for the purpose of raising the temperature of the air to a degree that the diffuser arrangement will effect a final complete vaporization.

While the value of improved distribution at all altitudes cannot be overestimated, there is no separation from the supercharging factor on the General Electric Company superchargers. This system provides positive supercharging and improved distribution at sea-level as well as makes it possible to maintain sea-level power at high altitudes when desired.

Atmospheric pressure at sea-level being approximately 14.7 lb. to the square inch and but 10 lb. to the square inch at an altitude of ten thousand feet, the compression of an engine is affected as the altitude is increased above sea-level, and the power output is decreased. On an engine operating at about 2000 r.p.m. and provided with a supercharger employing the General Electric Company system with a 7 to 1 gear ratio the supercharger impeller will rotate about 14,000 r.p.m. This speed will provide a pressure rise of about 3½ in. of mercury above atmospheric pressure at the inlet valves. In the absence of a supercharger, the pressure at the inlet valves would be about 1½ in. of mercury below atmosphere, so that the net increase of pressure due to supercharging is about 5 in. of mercury, providing an increase in power over the unsupercharged engine of approximately 20 per cent. Individual cases vary somewhat from these figures, according to the ability of the engine to continuously deliver the given amount of power with the throttle wide open. There is no regulating mechanism of any kind, except the conventional butterfly valve at the end of the carburetor and just preceding the supercharger inlet. This butterfly valve is opened or closed as change of power is required, just as in an unsupercharged engine. The supercharger is giving its full pressure rise at all times and some of this is wasted at part throttle. However, the power loss is not appreciable and the gasoline consumption per unit of power of supercharged engines is slightly better than that of engines not equipped with a supercharger. For some engines, superchargers are driven with increased speeds by use of gear ratios of from 10 to 1, to 14 to 1, giving impeller speeds of from 20,000 r.p.m. to 28,000 r.p.m. The engine will usually not stand up under the

increased power which could be obtained with wide open throttle under such circumstances. To prevent shortening the life of the engine the throttle is not fully opened until the engine has reached considerable altitude. Such engines will then give full sea-level power at altitudes up to about 12,000 ft. Some arrangement, however, must be made to remind the pilot that the throttle is not to be opened wide near sea-level, except for short periods or in an emergency.

All Pratt & Whitney engines equipped with the General Electric Company high-speed superchargers are designated by a yellow band on the intake pipes. In addition an extra plate is furnished with each of these engines which should be fastened on the instrument board of

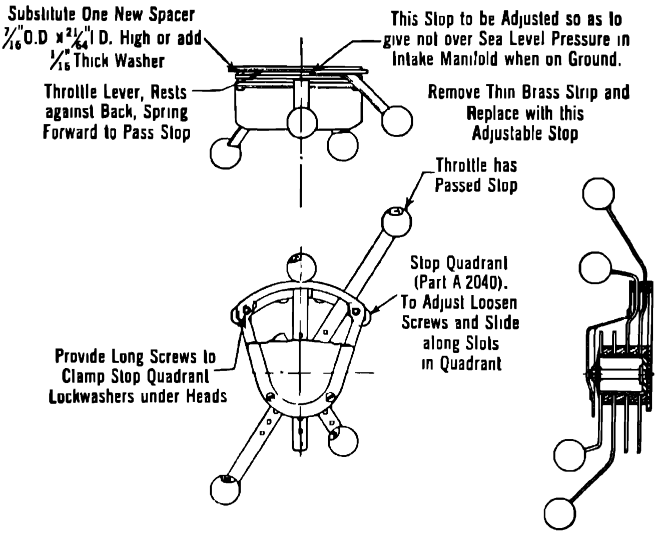


FIG. 73. Throttle Stop.

For use with engines equipped with high-speed supercharger

each plane equipped with them, and in such a position as to be plainly seen by the pilot.

All planes having these engines should have the pilot's throttle lever equipped with a stop, arranged to warn the pilot against opening the throttle beyond a point which will produce sea-level pressure in the manifold. A $\frac{1}{8}$-in. pipe thread connection is provided on the No. 5 outlet connection on the Blower Section casting to which a suitable altitude pressure gage should be attached, which will guide the pilot in operating the throttle. This stop should be made so that the pilot can, without special precaution, quickly close the throttle if necessary, without being

hampered by the stop, and should be fixed in such a manner as to positively warn him when opening. A suggested method of accomplishing this is illustrated in Fig. 73. The Pratt & Whitney Aircraft Company is prepared to furnish this type of throttle stop. This throttle stop can be set when the engine is being ground-tested before its initial flight, and should be so set that the altitude gage will not show below sea-level pressure when the throttle is against the stop and the plane on the ground. This instruction, of course, assumes that this test will be made at a station somewhere near sea-level and will not apply to flying fields or stations which are more than 5000 ft. above sea-level.

The impeller wheels of the high-speed superchargers rotating from 14,000 to 28,000 must be manufactured with great care, and the General Electric Company has a special department devoted to this work. The material, which is forged aluminum or forged magnesium, must be carefully selected and properly treated. The design must be such as to operate with high efficiency at the rotative speed mentioned. All the parts of the supercharging system of the General Electric Company are made by the engine manufacturer, with the exception of the high-speed impeller. The impeller is supplied by the General Electric Company. Summarizing the advantages of this supercharging system, they are as follows:

1. Improved vaporization and completely satisfactory distribution of the charge of gasoline and air to any number of cylinders, with the use of a single-barrel carburetor.
2. Increase of power at sea-level of any engine up to the maximum amount of power which the engine design will permit.
3. Possibility of maintenance of sea-level power up to appreciable altitudes, at which the plane speed would otherwise be greatly decreased.
4. Possibility of increase of power above normal sea-level power during take-off and emergencies.

INSPECTION AND SERVICING OF THE GENERAL ELECTRIC SUPERCHARGER ON PRATT & WHITNEY ENGINES

Disassembly of Accessory Section.—The accessory section should never be disassembled unless it contains some known defect. All the gears may be examined by removal of the fuel and oil pumps after the main case has been dismantled. The supercharger impeller may be inspected by removing the four-screw plate on the intake elbow above the carburetor.

If a complete disassembly is necessary, turn the assembly stand so that the accessories are in their normal position. Then remove the

magnetos, starter, and carburetor and take off the magneto drive bearing covers. Next remove the three drive shafts, as follows:

The starter jaw is held on by a nut at the rear end. Remove this

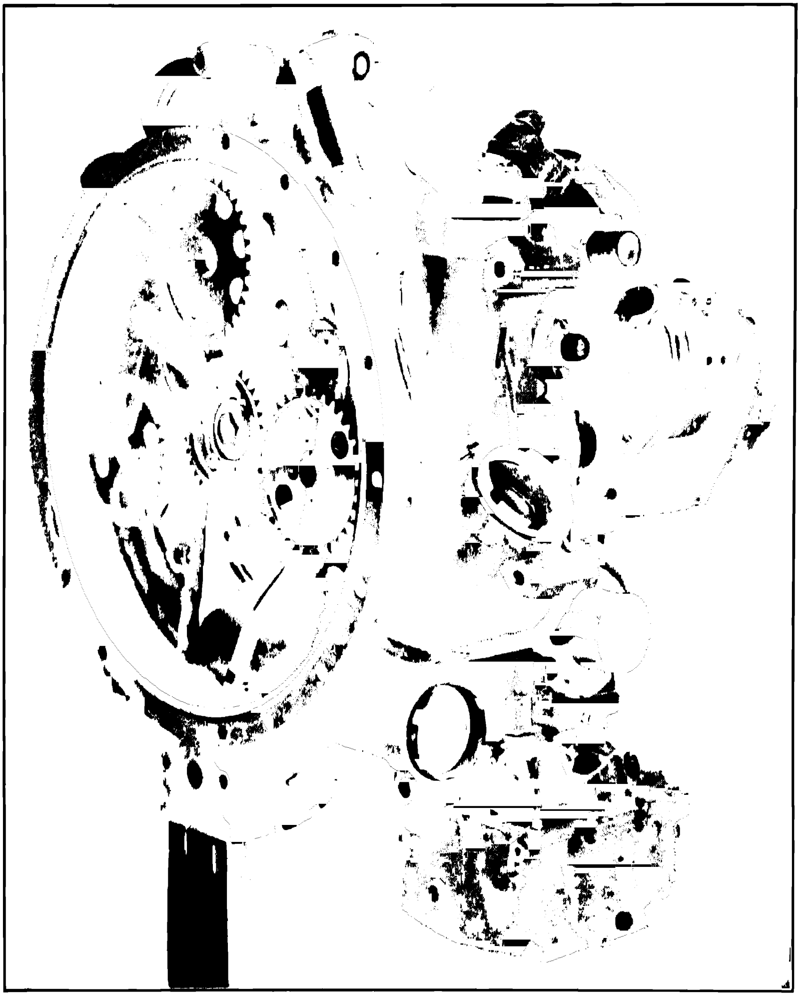


Fig 74 —The Rear Section of the Hornet

nut and tap the shaft out toward the front Each magneto shaft coupling is held on by a cap screw in the rear of the shaft. Removal of the coupling and taking out the key allow the shaft to be pushed out forward. Removal of the fuel and oil pumps with their bevel gears will

permit the magneto shaft bevel gears to be taken out. The gun synchronizer couplings are screwed on their shafts and held by straight pins covered with spring steel snap rings. These shafts are taken out through the pump openings. With the shafts out, turn the rear section uppermost, and it may then be unbolted from the blower and these two parts separated by tapping with a soft hammer. *Do not pry apart with screw-drivers.*

Care must be taken to draw the rear section straight up because the three accessory shaft bushings which are pressed into the rear section also fit in the blower section. When setting the rear section down, *avoid resting it on the projecting oil pipe.*

The engine can be fitted with blower gearing of different ratios,

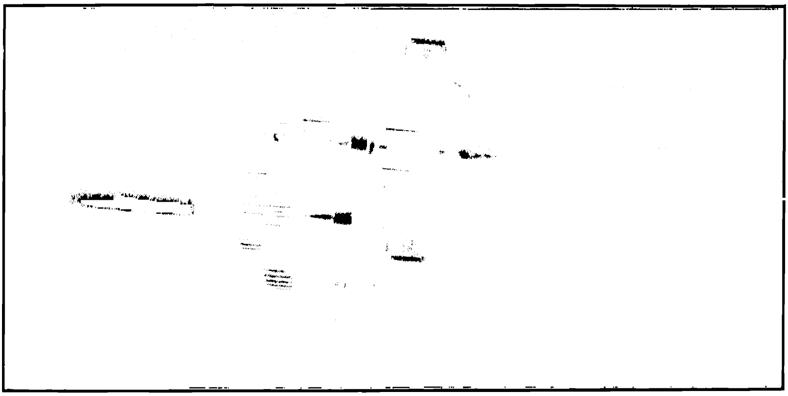


Fig 75.—Blower Gear Holder and Impeller Nut Wrench for Hornet Supercharger.

according to the purpose for which the engine is used. The earlier engines had 5 to 1 ratio non-floating gears. All standard engines have 7 to 1 ratio gears with a floating drive gear. Some engines have 10 to 1 ratio gears. These are distinguished by a yellow band on the intake pipes of the two upper cylinders and a supercharger warning plate on the blower. A plate is also furnished for installation in the cockpit, as a reminder to the pilot, as previously mentioned.

Non-Floating Gears.—In handling the 5 to 1 non-floating gears, proceed as follows:

To disassemble the blower gearing take out the impeller nut pin and unscrew the nut with the fish-tail screw-driver. **This nut has a left-hand thread.** Use the special tool provided for holding the gears. Do not insert a screw-driver between the teeth for this purpose. Take off the impeller, using the special puller. The aluminum cover over the

blower shaft bearing may now be removed. The blower intermediate shaft rear nut should be taken off, followed by the front nut on the same shaft. The blower gear holder is used during this operation, as well as when removing the blower nut. The double gear is now free and can be taken out, after which the intermediate shaft may be withdrawn. Removing the front nut from the blower impeller shaft allows this shaft

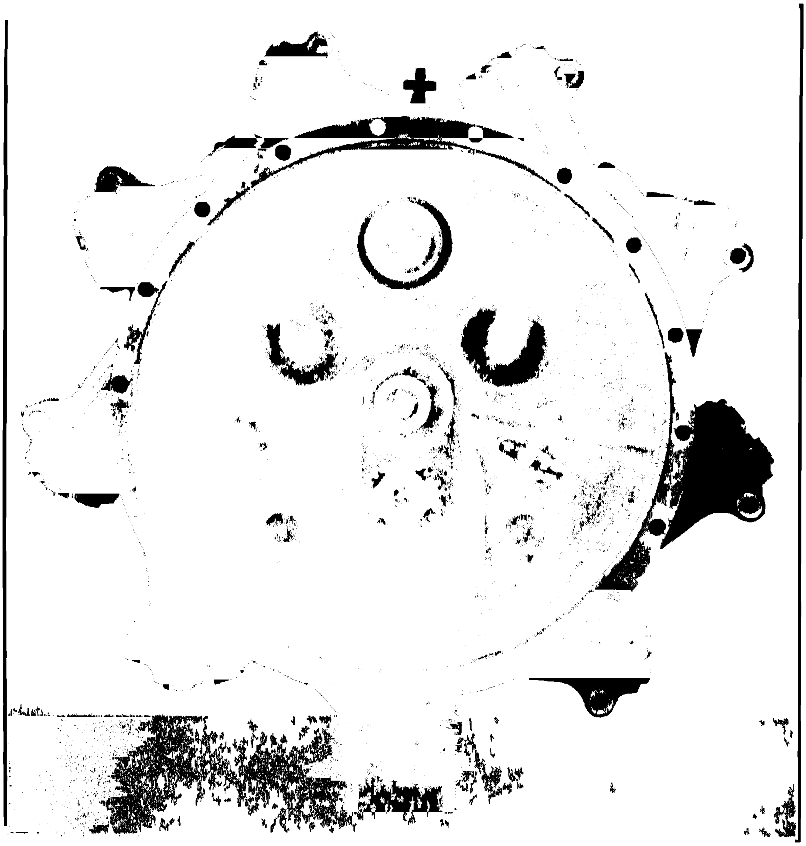


FIG 76 Blower Clutch Assembly for Hornet Engine

to be taken out towards the rear, together with one of its bearings. In order to remove the other bearing it is necessary to take out the bearing cage. To do this, press out the cage with an arbor shaped to fit it. If the cage is excessively tight, apply a gentle heat to the boss. When replacing the cage, the slot in its rear edge must be lined up with the slot in the blower section. *Caution: Excessive heat will spoil the bearing.*

Floating Gears.—In the floating-gear assembly, the crankshaft gear does not comprise two spur gears as in the solid drive, but has a single gear which takes care of the starter and magneto drives. On the inside of this gear are clutch teeth which engage the blower driving gear. The driving gear is independent of the crankshaft and floats on its own bronze bearing, supported by the blower section of the crankcase. Removing the six screws on the face of the bearing will allow the bearing and gear to be withdrawn.

To remove the nuts on the impeller shaft and the intermediate shaft, fix the gears in position with the "blower gear holder," which has internal teeth to slip over the intermediate pinion. If the intermediate shaft should turn in its gear, it may be held by means of the slot in one end.

The intermediate shaft has to be driven out of the double gear (forward) before the gear can be taken out of the case.

The gears and bearing should not show excessive wear. The impeller should be a good fit on the splined shaft. Make sure the oil drain holes and grooves are open. Test the passage which supplies oil to the blower gears and especially the oil feed to the floating gear bearing.

Clutch for Blower Drive.—The high rotative speed of the blower impeller gives it considerable flywheel effect in spite of its light weight. To absorb any shocks due to sudden changes of speed, a slipping clutch is provided between the crankshaft and the floating gear which drives the blower.

The clutch as used beginning with the Series A-1 Hornet Engine consists of six surfaces. This differs from earlier clutches in having four friction plates instead of two. The clutch is assembled inside the crankshaft gear as shown in the clutch drawing. The clutch comprises: 2144, a steel plate to provide a wearing surface; 2549, the fixed clutch plate, which is a toothed bronze piece piloted in the crankshaft gear, forming the driven member of the clutch and driving the floating blower gear by its teeth; two steel friction plates, 2548, keyed to the driving member; two bronze friction plates, 2547, keyed to the toothed piece; 2549, the fixed clutch plate which presses the other plates together and which is keyed to the crankshaft and has a pilot in the central hole of the crankshaft. The blower clutch spring cage 2544 fits into the fixed clutch plate and into the pilot on the crankshaft. A spring 2545 exerts pressure on the fixed clutch plate and is anchored by a bolt 2546 screwed into the rear half crankshaft from the front side.

To disassemble the clutch, undo the small nut at the rear and remove the spring. The plates will stick together on account of the oil on them. The puller PWA-153 should be screwed into the spring cage which can

be taken out by a direct pull or by screwing the puller all the way in until it hits a shoulder on the central bolt and jacks the plate out.

An oil jet in the crankshaft lubricates the clutch, and should be checked to see that the passage is clear. The central bolt need not be removed from the shaft. Note, however, that if for any reason this bolt should be replaced, it must be locked in place by punching the flange into a small countersink in the crankshaft. After the clutch parts have been taken out of the crankshaft gear, the latter may be removed by taking out the flat-head screws which hold it to the crankshaft.

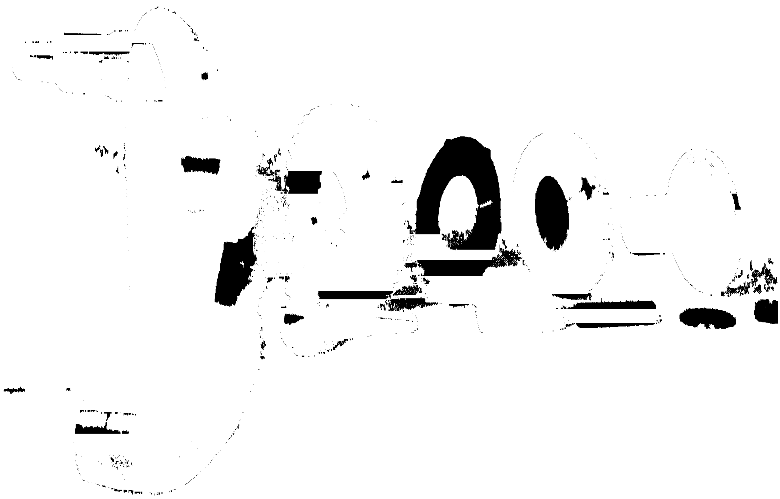


FIG. 77.—Floating Gear and Clutch Parts of Hornet Engine.

Assembling Clutch.—The various parts should be inspected to see that the friction surfaces are smooth and that there is no noticeable wear on the keys which prevent turning. The teeth which engage the blower drive gear should be examined. It is necessary to have a good bearing over the whole surface of the clutch plates. This can be tested on a surface plate smeared thinly with Prussian blue. Press each clutch plate all around with the fingers to insure good contact with the blued plate. If necessary, the steel plates can be trued up on a surface grinder having a magnetic chuck, or they can be lapped. The bronze plates must not be lapped, but can be scraped. Used plates sometimes show a ridge near the outside edge where they overlap the steel plates, and this should be carefully removed by filing before any attempt is made to scrape them to a perfect bearing.

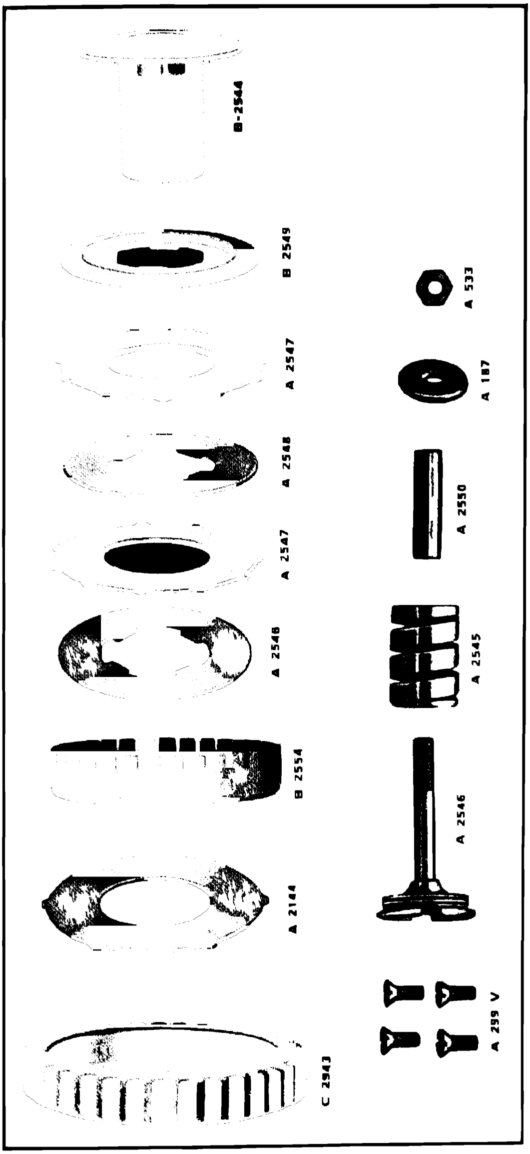


FIG. 78.—Clutch Parts of Hornet Engine

The clutch spring must not show less than 1500-lb. load when compressed to a length of $1\frac{25}{32}$ in. After making any necessary replacements, clean and oil the parts and put them together in the reverse order to disassembly, having first assembled the two halves of the crankshaft and put on the rear bearing and gear.

See that the locating teeth or projections on the outside of the various clutch plates fit into the recesses provided for them. Smearing the plates with heavy oil will help stick them together until the nut can be put on.

Be sure to put in the spacer that goes inside the spring, and screw the nut up tightly against this spacer. The length of the spacer determines the spring pressure and hence the holding power of the clutch. Proper adjustment of the clutch is important, for if it is too tight, other parts may be overloaded, and if too loose, it will slip, causing a loss of power at full engine speed.

Adjusting Clutch.—Hold the crankshaft in a soft-jawed vise so that the clutch overhangs the edge of the bench. To turn the clutch it is necessary to have a gear similar to the floating blower gear, with a lever arm attached to it. See Fig. 79. With the arm horizontal the clutch should just sustain the following weights hung at a distance of 27 in. from the center of the crankshaft:

	Pounds
Wasp C, 7 : 1 Blower	75
Wasp C, 10 : 1 Blower	100
Hornet A and A 1, 7 : 1 Blower	85
Hornet B, 7 : 1 Blower	100

The clutch should be tight enough so that with the lever slightly above the horizontal and the weight hanging as above, striking the top of the lever with the hand will cause the weight to fall a couple of inches and then stick again. If it is necessary to increase the tension of the clutch spring, take out the spacer which goes inside the spring, and face it off slightly, keeping the ends square. Before testing the clutch it is well to take hold of the lever arm and work it back and forth, to squeeze out surplus oil.

In performing the above operation, care should be exercised to see that the teeth on bronze gear are not unduly strained or injured by the levers not being in proper engagement. This may result in breakage of these teeth in operation.

Assembling Blower Section.—After the blower section has been thoroughly cleaned, it can be bolted to the assembling stand with the oil sump connection at the lowest point. The blower impeller shaft and bearings may then be put in place and next the blower intermediate shaft.

The intermediate shaft gear should be put on, and then, by using the blower gear holder furnished in the station tool equipment, the rear nut of the intermediate shaft and the front nut of the impeller shaft can be properly tightened. These two nuts are secured by cotter pins. The

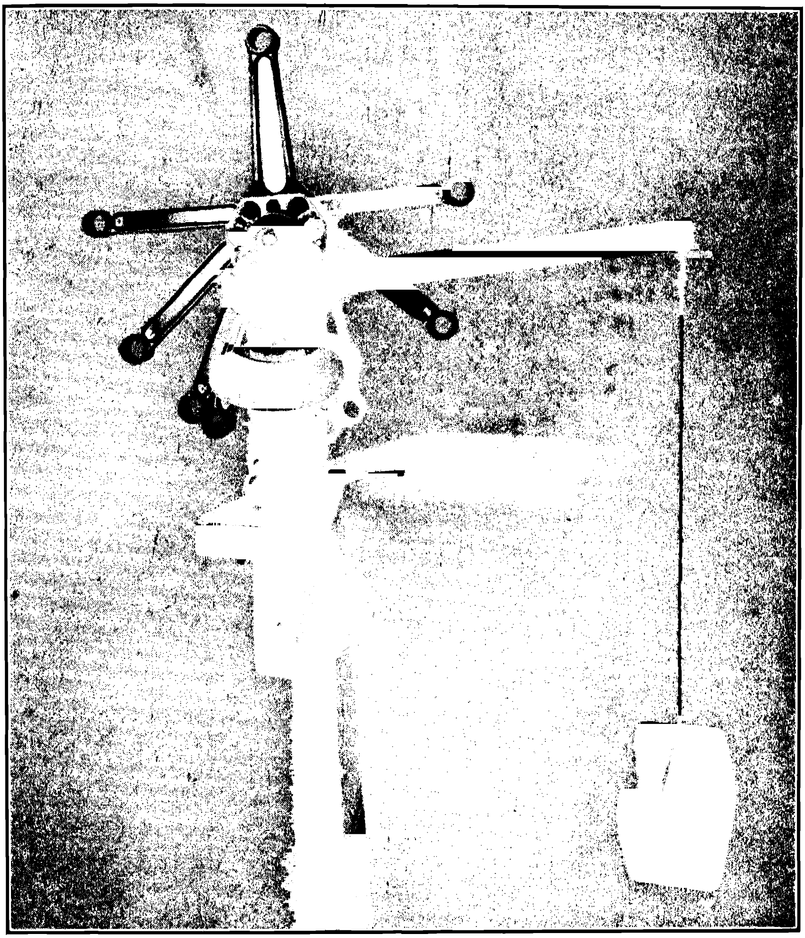


FIG. 79.—Testing Clutch Tension.

bearing cover is held against the blower casting by eight screws, and a gasket is used between the cover and the casting. A new gasket should be used and shellacked to the cover, which should be carefully cleaned. Oil the other side of the gasket. See that the oil slinger is in place on the impeller shaft. After the cover has been made fast and wired, the im-

peller is pushed on the shaft and the cone-shaped impeller nut secured. A special screw-driver for tightening this nut is supplied, and the blower gear holder is used to hold the gears stationary while this is being done. *Do not use a screw-driver between the gears to hold them,* but use the gear holder which is made for the purpose. Be sure that the impeller nut is screwed up as tight as possible and then put the safety pin in place. This pin should be made from an eightpenny nail and is bent over at both ends to hold it in place. Turn the blower section over so that the front side is on top. Examine the floating blower drive gear and its bushing. The latter should be a tight fit on the boss of the blower casting, and in any case, not more than 0.0005 in. loose on the diameter. The bearing surfaces of the bushing and gear must be in good condition, and the clearance between them should not be more than 0.008 in. Be sure that the oil passage which feeds this bearing is open and that the holes register. Oil the gear, put it on the bushing, and tap the bushing into place, fastening it with the six small screws. These must be wired. The end clearance between the gear and the flange of the bushing should not be more than 0.010 in. (These directions are of course unnecessary on engines having a double gear on the rear of the crankshaft.) Put the pressure oil pipe in place. While the casting is in this position, make sure that the various plugs in the front face of the blower are tight. Any looseness can be remedied by carefully peening the casting around the edge of the plug. When everything is in order here, reverse the assembly stand, so that the rear side of the blower will be uppermost. The rear casting may now be placed upon the blower.

EXHAUST-DRIVEN SUPERCHARGERS

For many years there was considerable development work upon superchargers driven by the engine exhaust. These chargers, attached to water-cooled engines, enabled flights to very high altitudes. After a great deal of experimental work, satisfactory superchargers of this type were installed on airplanes and are now in general use.

These exhaust-driven superchargers comprise centrifugal compressors which in general design are identical with the geared chargers described, but are driven by turbine wheels operated from the engine exhaust gases. They are primarily suited for flights at altitudes in excess of 20,000 ft.

At an altitude of 20,000 ft. the atmospheric pressure is one-half the pressure existing at sea-level, and at an altitude of 35,000 ft. it is but one-quarter sea-level pressure. At these extreme altitudes, the engine charge is reduced proportionately; therefore, the engine power is like-

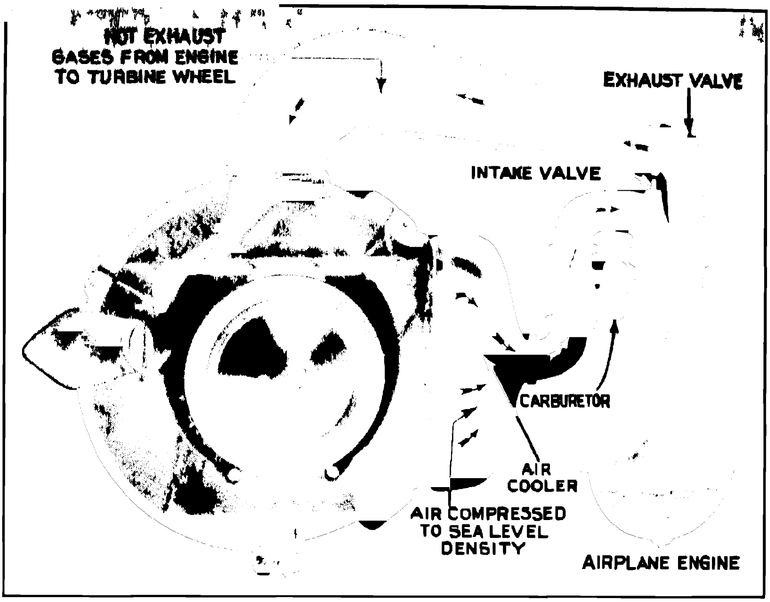


Fig. 80.—The Principle of Exhaust-driven Superchargers

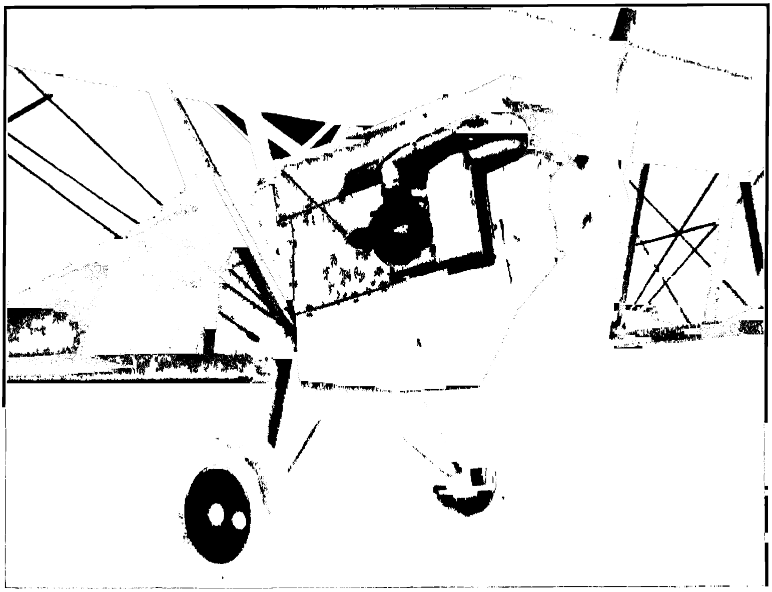


Fig. 81.—G-E Exhaust-driven Supercharger on an Army Experimental Airplane.

wise decreased proportionately. The object of the exhaust-driven supercharger is to maintain sea-level pressure at these extreme altitudes.

In Fig. 80 it will be noted that the engine exhaust is completely enclosed in the manifold. When the engine is operating at altitude, there is maintained with this exhaust manifold the full sea-level pressure. The exhaust manifold leads the exhaust gases to a nozzle box which directs the exhaust gases on to the turbine wheel. The turbine is always located directly in the atmosphere without a casing of any kind. The gases pass from the nozzle box, wherein there is full sea-level pressure, to the high-altitude atmosphere at low pressure, resulting in a velocity which furnishes the power to drive the turbine wheel. On the same shaft as the turbine wheel is the impeller of the centrifugal compressor, which serves to compress air from the low pressure at the high altitude to full sea-level pressure, at which it is delivered to the engine. Therefore, even though the plane is at high altitude, the engine exhausts at normal sea-level pressure and receives its charge at normal sea-level pressure, so that it necessarily delivers normal sea-level power.

The exhaust manifold, nozzle box, and turbine wheel operate at very high temperatures. These exhaust-driven superchargers have a rated speed of 25,000 r.p.m., and the turbine buckets must withstand the centrifugal force at this speed while red hot. A 20,000-ft supercharger delivers about 50 h.p. at the shaft, and the complete outfit weighs about 65 lb. An air cooler weighing an additional 20 lb. is necessary to reduce the temperature of the air after compression.

CHAPTER IX

LUBRICATION

The most important factor in the operation of aircraft engines is lubrication. The minimizing of destructive friction insures obtaining the longest possible life for the aircraft engine, subjected as it is to high temperatures, and high bearing speed over long periods. The ideal strived for in the lubrication of frictional surfaces in an engine is the complete separation of opposing metallic surfaces which are in motion. If these frictional surfaces can be absolutely separated at all engine temperatures and speeds, wear is reduced to that which takes place from friction actually created by the oil.

The designing and constructing of an aircraft engine are little labor in comparison with the experimental and research work involved once the engine is assembled and ready to test. To insure long life and dependability, various clearances at the bearings and other frictional surfaces must be tried until clearances which will insure the correct volume of oil under the right pressure have been determined.

The individual characteristics of the engine design make necessary long experimental work to determine the proper grade or body of oil best suited to meet the peculiarities of a particular engine. An oil which has proved wholly satisfactory in one type of engine may fall short of the requirements of another engine. Therefore, individual opinions which have been reached through experience with certain oils should be set aside if they are contrary to the recommendations of the engine manufacturer who has devoted time to exhaustive research in order to determine the lubricant best suited to his product.

The most common system of aircraft engine lubrication met with today is the *force-feed dry sump,* in which oil under pressure is forced to the engine bearings. The bleeding of the bearings creates a mist which oils the cylinder walls and pistons, and is then caught in a sump which is kept dry by a scavenger pump. The scavenger pump returns the oil to a reservoir external from the engine.

The *force-feed wet-sump* system differs from the *dry-sump* system to the extent that the sump in which the oil falls by gravity after being bled from the bearings is also the oil reservoir. No scavenger pump is

required in the wet-sump arrangement, and there is no external oil reservoir. This system is used in the well-known Curtiss OX-5 Engine, and in the Cirrus Engine.

In the OX-5 Engine, oil is taken from the lowest point of the oil sump and is forced into the rear end of the camshaft, which is hollow. At the point of the oil's entering the camshaft, there is an adjustable oil pressure relief valve for controlling the oil pressure. The oil is forced through the hollow camshaft, camshaft bearings, and through tubes to the crankshaft bearings. From the crankshaft bearings the oil is forced through the hollow crankshaft to the connecting rod bearings; the oil thrown off from the bearings lubricates the pistons and cylinder walls. The timing gears are lubricated by the oil which passes directly through the hollow camshaft. The oil thrown off by the bleeding bearings returns to the sump by gravity.

LUBRICATION SYSTEM OF THE PACKARD 3A-1500 AND 3A-2500

The Packard twelve-cylinder, V-type Upright Aircraft Engine models 3A-1500 and 3A-2500, have identical lubrication systems. The engines operate on the dry-sump principle, using an external oil tank and oil cooler.

Oil is led up to the pressure oil pump through the oil "in" line ($1\frac{1}{4}$ in. O. D. tube connection) located at the bottom of the oil pump body. The oil flows through a fine-mesh screen which is readily accessible by removing the hexagon-head screw holding the oil strainer cover in place on the left side of the oil pump.

After flowing through the oil screen the oil is led into the pressure pump and is forced out either through a pressure line leading to the engine bearings or past a relief valve and through the oil "out" connection leading back to the tank. In the model 3A-2500 engine a fine-mesh screen may be provided on the discharge side of the pressure pump, the suction screen on this model being of coarser mesh.

Oil under pressure is led to the oil manifold extending the full length of the engine and located at the top of the crankcase by means of passages provided in the oil pump body and crankcase oil pan. These passages consist of steel tubes pressed in the aluminum castings, and "matched" joints are provided between the oil pump body and the crankcase oil pan and between the oil pan and crankcase, respectively.

Care should be taken that clear holes are provided in the gaskets at these two points to prevent an obstruction to the oil supply reaching the engine. Vertical tubes are pressed into each crankcase main bearing wall, these tubes communicating with the horizontal manifold referred

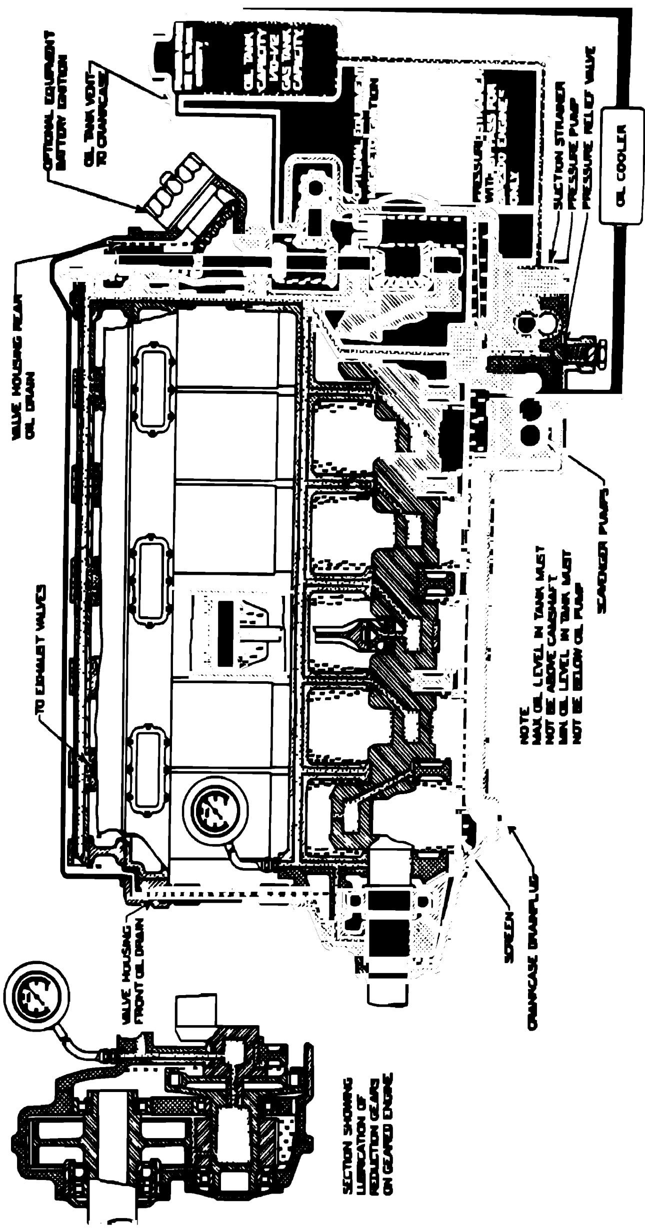


FIG. 82.—Lubricating Chart of Packard Aircraft Engines Models 1500 and 2500.

to. It should be noted that all of these oil connections are permanently pressed in place, preventing the possibility of loose connections developing in service.

The main bearing upper halves are drilled and furnished with hollow dowels which permit the flow of oil through the metering groove provided in these bearings. Steel tubes are pressed into the crankshaft and terminate at one end in the main journals in line with the bearing metering groove, and at the other end communicate with the hollow crankpins. These crankpins are plugged at both ends by means of duralumin plugs locked together with a through bolt, and an oil feed hole is drilled in the crankpin to lead the oil to the connecting rod bearing.

A connection for the oil gage line is provided at the rear end of the crankcase. This is a change from the previous models, in which it was necessary to bring the gage line back the entire length of the engine. At the rear end of the crankcase, a tube is provided which terminates in a $\frac{1}{4}$-in. internal pipe thread into which is screwed a tee provided with connections for the two oil lines leading to the camshaft housings.

The timing gear bearings are lubricated by the oil passages, each bearing being positively fed from the main lubricating system.

The camshafts are lubricated through oil passages leading through the rear end of the valve housing and through a matched joint between the rear camshaft bearing and the housing. This rear camshaft bearing is provided with a continuous groove, and the oil flows into the camshaft through two holes provided in the camshaft in line with this groove.

The camshafts are hollow and plugged at both ends and have oil holes provided in line with each of the seven bearings. These holes are specially located in the bearings adjacent to the exhaust cam followers so as to register with vertical passages in these particular camshaft bearings at such a time as the toe of the adjacent exhaust cam is at its highest point, that is: 180 degrees from the valve wide-open position.

In this manner oil under pressure flows through the camshaft and through the camshaft bearings and into the cam follower guide.

The exhaust valve stems are hollow and fitted with a $\frac{3}{16}$-in. steel tube which is pressed into a neck-down section of the valve stem at the upper end and is brazed to a $\frac{1}{8}$-in. pipe plug at the lower end through which this tube is inserted. Three horizontal holes are drilled near the lower end of the tube, and the valve stem proper is provided with two horizontal holes just below the necked-down portion. In this manner oil introduced under pressure at the upper end of the valve stem flows down inside the tube out through the holes at the base and up around the outside of the tube to the outlet holes in the valve stem. When the camshaft revolves, the exhaust cam depresses the cam follower, and the

oil which is trapped in the cam follower guide is forced through the exhaust valves in the manner indicated, thus cooling the valves and greatly prolonging the period between valve-grinding operations.

Return Oil System.—The excess oil thrown from the connecting rods and main bearings, after lubricating the pistons, collects in the lower half of the crankcase or oil pan. The oil thrown out from the camshaft bearings and the oil pumped through the exhaust valves collects in the valve housing compartment and drains back to the oil pan through drains provided both at the front and rear of the engine.

When the front end of the engine is high, as in a plane with the tail on the ground or when climbing, the oil from the valve housing compartment returns to the crankcase through generous cored holes, provided in the upper camshaft drive housings. This oil, together with the oil returned from the various timing gear shaft bearings, flows through two oil traps provided in the horizontal web extending across the timing gear compartment just above the crankshaft. The purpose of these oil traps is to prevent crankcase vapors, consisting of products of combustion which have leaked by the pistons, from rising into the timing gear and camshaft compartment and causing rusting of these parts due to condensation.

After flowing through these oil traps, the oil collects in the oil pan. When the front end of the engine is low, as in gliding or diving, the oil from the camshaft housings flows to the front end of the crankcase through the oil return tubes provided on the outside of the engine at the forward end.

The oil which collects in the oil pan or sump passes through the screen which covers the entire bottom portion of the oil pan and is returned to the outside oil tank by means of either or both oil scavenging pumps provided in the pump unit. These two scavenging pumps are formed by enclosing the three spur gears which are mounted respectively on the water pump shaft, the fuel pump driving shaft and the oil pressure pump shaft. The intermediate and forward or oil pressure pump driving gear combined form a scavenging pump which drains the rear end of the crankcase, the oil flowing to this pump through a hole provided in the gear cover of the scavenging pumps. The intermediate and the rear gear which is mounted on the water pump shaft combine to form a scavenging pump for the forward end of the crankcase, a pipe being clamped to the bottom of the oil pan and extending to a small sump at the front end of the oil pan for the purpose of collecting this oil and delivering it to the rear scavenging pump through suitable passages formed by a matched joint between the pump unit body and the crankcase oil pan flange.

External Oil System.—Two $1\frac{1}{4}$-in. hose connections are provided on the oil pump for the "oil in" and "oil out" connections, respectively, these markings being cast on the oil strainer cover so as to indicate the purpose of the two connections.

The oil should be led through a suitable oil cooler, with a distance thermometer placed preferably in the circuit, before the oil passes through the cooler, but in any case the thermometer should be distinctly marked as to whether it indicates "oil in" or "oil out" temperature. The oil cooler or regulator should have a cooling surface of about 25 sq. ft. for the model 1500 engine and about 40 sq. ft. for the model 2500 engine, and it is important that this oil cooler should be built amply strong to withstand 150 lb. per sq. in. pressure, which may be encountered during the first few minutes of running an engine with congealed oil in extremely cold weather. The oil cooler should also have suitable drains for draining both the oil and water (if used) sections.

The oil should be discharged into the external oil tank near the top of same, and this oil tank should have a capacity of between $\frac{1}{10}$ and $\frac{1}{12}$ of the gasoline capacity of the plane, this value excluding an allowance for expansion amounting to an additional 10 per cent of the volume. The lowest part of the oil tank should preferably be arranged to be slightly higher than the inlet connection to the oil pump.

The top of the oil tank should be vented to either of the connections provided at the rear end of the crankcase or at the front, whichever may be more convenient, this vent pipe being not less than $\frac{1}{2}$ in. O. D. and the piping being as direct as possible, avoiding any low points in which congealed oil might collect in cold weather.

The lowest point on the oil tank should be connected to the "oil in" connection on the oil pump unit by means of a $1\frac{1}{4}$-in. O. D. pipe. Special care should be used to insure that all external oil pipes be as direct as possible and free from sharp bends, and a suitable drain should be provided at the lowest point in the system.

Where the oil lines between the oil tank, oil cooler, and the engine are necessarily long, they should be water-jacketed for their entire length, and this procedure is also advisable even when the lines are short so as to promote the flow of oil when in a congealed condition by means of hot water circulated by the engine.

OIL PRESSURE

The clearances at the engine bearings, the grade of oil used, the temperature of the oil, the speed of the oil pump, and the adjustment of the oil pressure relief valve, are the factors governing oil pressure. It

should be obvious that a variation of any of these factors will result in a change in oil pressure. The engine builder, having worked out his engine bearing clearances and oil pump speed, as well as having chosen an oil which he has found to be suitable for his engine, adjusts his oil pressure relief valve so as to supply the bearings with the volume of oil sufficient to form a close film of oil and to cool the bearings. The pressure which results becomes the normal oil pressure for that par-

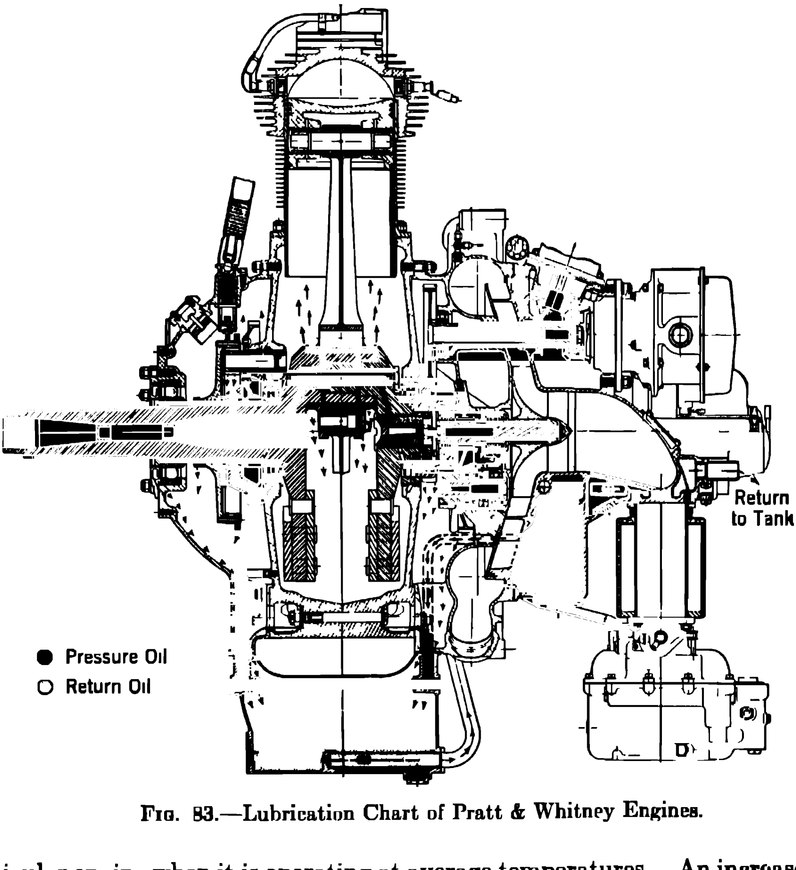


Fig. 83.—Lubrication Chart of Pratt & Whitney Engines.

ticular engine when it is operating at average temperatures. An increase in temperature thins oil, with the result that the oil flows more freely with a consequent drop in oil pressure; or, in the case of reduced temperature from normal, the oil becomes sluggish resulting in a rise in oil pressure. The effect of temperature due to climatic variations is a normal condition, and allowances must be made for changes in oil pressure when caused by this source.

The rise in oil pressure because of an increase of internal engine temperatures which is not due to climatic conditions indicates trouble, but in this case the oil temperature gage is the guide rather than the oil pressure.

LOW OIL PRESSURE

As previously pointed out, the oil pressure being governed by engine bearing clearances, grade of oil, temperature, speed of oil pump, and the adjustment of the oil pressure relief valve, it follows that these factors

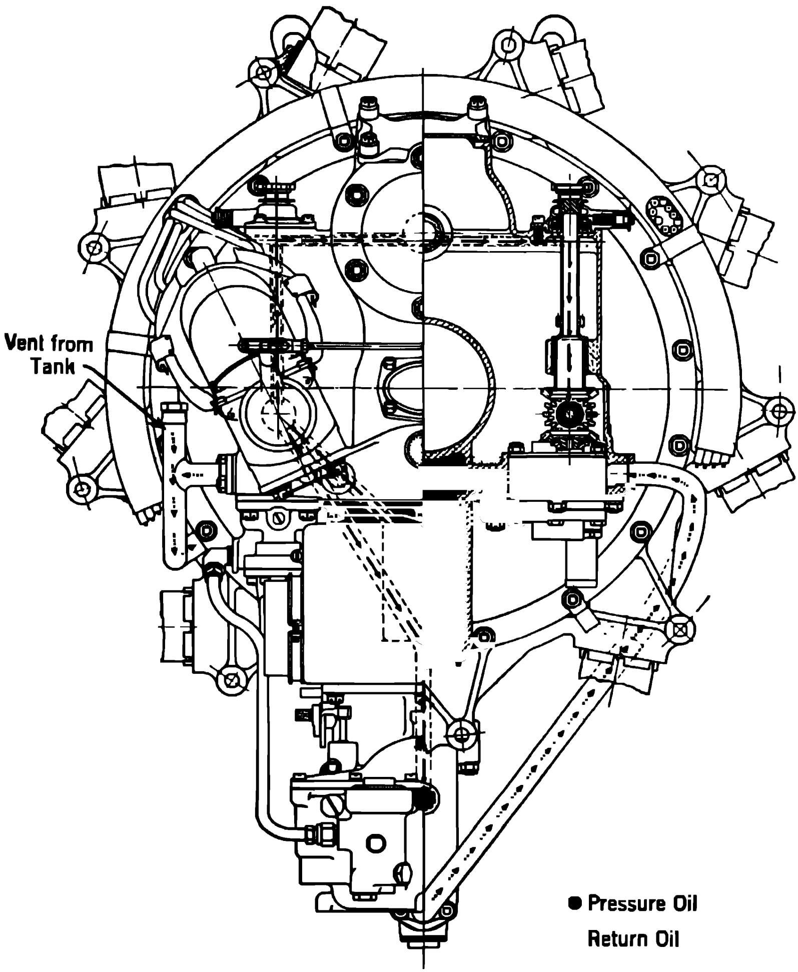


FIG. 84.—Lubrication Chart of Pratt & Whitney Engines.

must be considered when low oil pressure is encountered. Low engine speed means low oil pump speed. Therefore, *low oil pressure* as a trouble refers to the condition arising at wide open throttle. It is possible that the oil in the engine is old and has become thin by use and contaminated with fuel or that the grade of oil used is not correct. The oil screen may have become clogged, or a leak may have developed in the oil suction line. The oil pressure relief valve spring may have become weak or broken, or perhaps the valve is not seating. The trouble may be in the oil pump because of excessive clearance at the oil pump gears or an excessive clearance at one or more of the engine bearings which permits a free flow of oil by bleeding.

In the correcting of low oil pressure, the source of the trouble should be located, and in one case only should the oil pressure relief valve be tampered with, and that the cleaning of the valve and checking the spring tension. Under no circumstances should low oil pressure trouble be attacked by altering the adjustment of the relief valve. The cause of the low pressure should be determined and remedied. If the entire lubricating system is cleaned, oil suction lines checked for leaks, oil pump gear clearance corrected, if at fault, clean, correct oil placed in the reservoir, and another oil gage attached for checking the engine oil gage, and the low pressure still persists, this condition is an indication that there is an excessive clearance at some of the engine bearings which can only be remedied by an overhaul of the engine.

OIL TEMPERATURE

As explained under Oil Pressure, low oil pressure may indicate that the oil temperature is high, and high oil pressure indicate that the oil temperature is low. To judge the oil temperature by the oil pressure, however, is far from satisfactory. It is only through an intelligent reading of both the oil pressure gage and the oil temperature gage that a pilot may diagnose extreme variations and make his decision.

On an engine in which the desired oil temperature is 140° F. and the desired oil pressure 90 lb., assuming the engine is correct throughout, there will be a slight reduction in oil pressure as the oil temperature rises above 140° F., because of climatic conditions, just as there will be a rise in pressure above 90 lb. when the oil temperature drops below 140° F.

During flight if an abnormal rise in oil temperature occurs, for example, a temperature of 190° F., the oil pressure will drop considerably but not in proportion to the temperature rise. Therefore, the pilot with a pressure gage alone to guide him could remain in ignorance of the dangerous temperature reached by the oil. This abnormal rise

in temperature could be due to a shortage of oil in the reservoir, the shortage bringing about an overworking of the small amount of oil left in the system, or it could result from improper circulation of air through

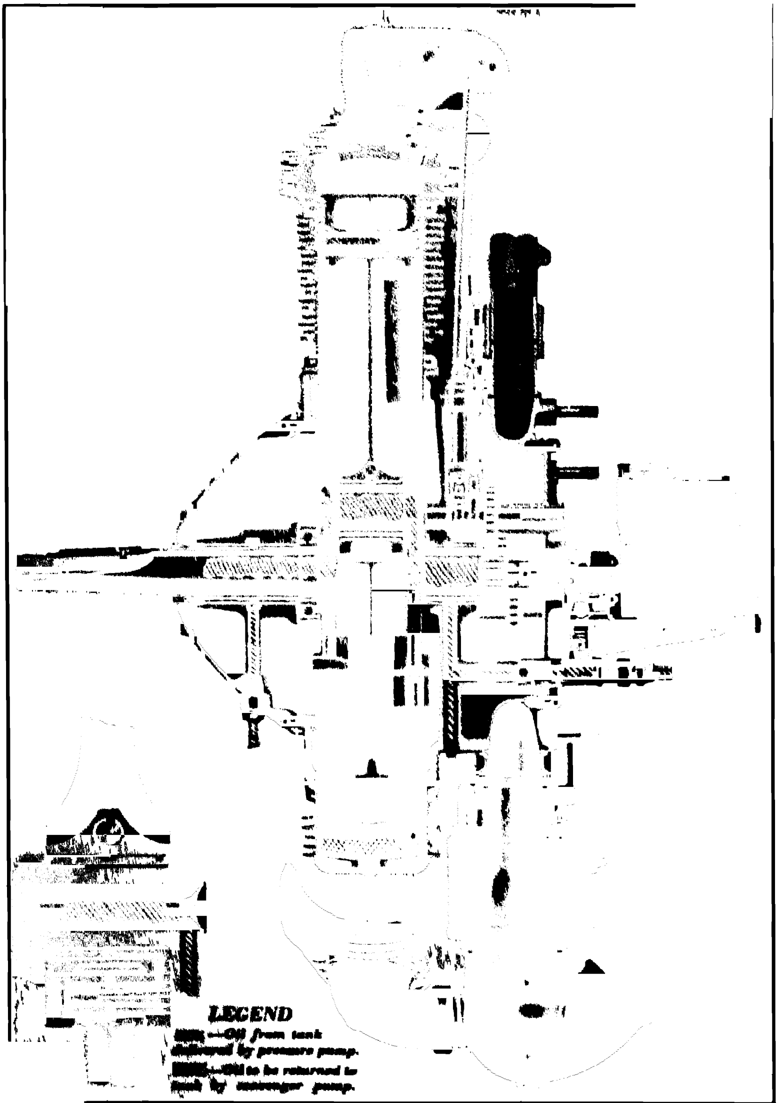


FIG. 85.—Lubricating System of the Kinner K-5 Aircraft Engine.

the oil cooler, if one is fitted to the system. The rise in temperature could likewise be caused by insufficient circulation of air around the engine crankcase because of incorrect cowling for high atmospheric temperatures. The trouble may also be due to an overheated bearing in the engine or to the failure of the scavenger oil pump. The oil temperature gage proves its value in these instances, and the warning it gives, as it approaches the danger point, enables the pilot to choose his landing, whereas the drop in pressure on the oil gage might not be accurately computed in terms of degrees of temperature, and a forced landing would result.

It is also possible for a new or reconditioned engine to have the bearing clearances so close that the oil pressure relief valve would be working constantly. This would cause the oil pressure to remain high while the oil temperature might have risen to the absolute limit, unknown to the pilot.

The oil temperature gage also has its value during the warming up of an engine, for it is inadvisable to take off until the oil has reached the temperature recommended by the engine manufacturer.

OIL TANK INSTALLATION OF THE HORNET ENGINE

The location of the oil tank will depend to some extent upon the general airplane design, but in all cases should be close to the engine so that short and relatively straight piping may be employed. This is of great importance because of possible damage to an engine due to frozen oil in long indirect lines. The tanks should be located at a level slightly above the oil pump so that the oil pump is never compelled to operate under a suction head. The oil tank may be as much as two, or at a maximum three, feet above the oil pump, but more than this may cause drainage of oil into the engine when the airplane stands for any length of time. Placing the oil tank forward of the firewall in the rear of the accessory compartment has been found very satisfactory.

Circulation of air over the oil tank must be provided. As the tank is located in the accessory compartment, the air which passes over the rear of the engine will aid in this, but it does not provide a sufficiency. For warm-weather operation a maximum of ventilation is required; in cold weather it is desirable to have no circulation. These conditions are best met by having adjustable air-inlet doors on the sides of the fuselage ahead of the oil tank, with corresponding provisions for taking the air out. In general, the arrangement of firewall and tank with respect to shape and location should be such that this air flow is facilitated. The use of finned tubing on the oil lines has been found to

be an aid in keeping the oil temperature at the desired condition in warm weather. In cold weather this finned tubing can be lagged or covered.

An expansion space of 10 per cent of the volume of the tank must be provided in the top. The filler cap on the tank should be placed on one side below this air space so that it is impossible for a careless mechanic to fill the tank above the proper level. The oil lines should be large, one inch in diameter at least, and should be annealed seamless copper tubing. A *large drain* reaching below the cowling and attached to the pipe leading from the oil tank to the pump at its lowest point, will be found highly desirable in facilitating the drainage of oil from the system.

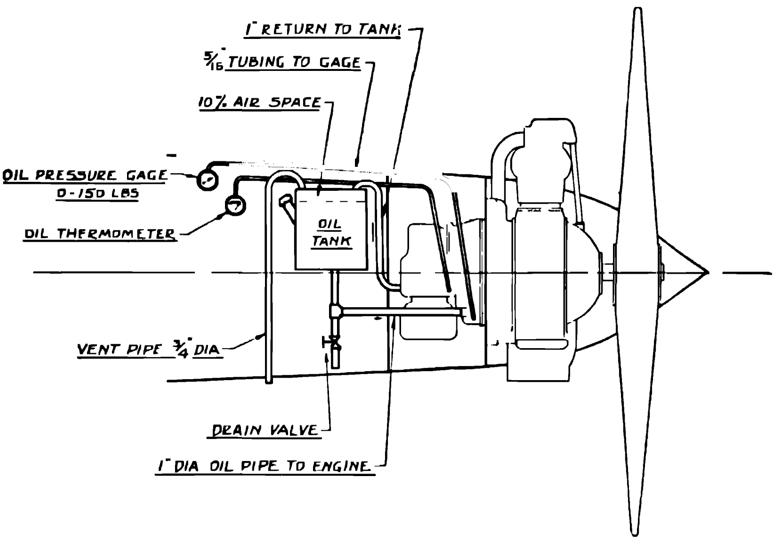


FIG. 86. Diagram of External Oil System for Pratt & Whitney Engines.

The vent to the oil tank should be at least $\frac{3}{4}$ in. in diameter. This can be connected by means of the fitting on the engine to the engine crankcase in case of necessity. This type of venting is, however, primarily designed to care for military installations which are compelled to operate during violent maneuvers, and it is not recommended that the oil tank be vented to the crankcase in other installations.

There is a drain plug in the bottom of the engine sump, and as this is the lowest point of the oiling system it should be kept accessible.

The oil strainer is at the rear of the engine, just forward of the carburetor. Provision should be made in the cowling and structure to get at this readily. The oil pressure relief valve is at the side of the strainer

chamber and faces toward the rear and the left side and should be made accessible.

The oil pressure gage connection is on the right side of the engine at the rear of the mounting flange and is tapped $\frac{1}{8}$-in. pipe thread. Five-sixteenth-inch O. D. copper tubing should be used, with a pig tail at the engine, and a 150-lb. gage. The oil thermometer connection is also on the right-hand side and is in the oil outlet passage. This is tapped $\frac{5}{8}$-in. 18 threads. The thermometer should read in degrees Fahrenheit to 212°, or in degrees Centigrade 100°.

SERVICING POINTERS

It is of the greatest importance to use an oil in an engine which has been recommended by the engine manufacturer. The engine manufacturer also recommends a particular oil for summer and for winter, and his instructions should be carefully followed.

Clean, fresh oil of questionable grade does not insure adequate lubrication. Economizing on oil is the poorest economy which could be practiced and always results in a greater expenditure in replacing prematurely worn parts. The best oil produced is not capable of withstanding the high temperatures in an aircraft engine without suffering a deterioration. Therefore, a cheap, inferior oil stands a small chance of giving any satisfactory service.

Frequent draining of crankcase oil is one of the most important duties in the care of an engine and contributes more to lengthening the life of an engine than any other single factor. No engine should be operated longer than twenty flying hours without draining the oil and replenishing it with fresh oil. In many cases, depending upon conditions, fifteen hours between oil draining will be advantageous.

In freezing weather the oil should be drained from an engine while the engine is still warm, and the oil should be preheated before being placed in a cold engine. The oil strainer should be carefully cleaned and wiped with lintless cloth at the time of each draining. The oil may be placed in cans which are sitting in boiling water, but the oil should not be heated to more than 150° F.

The oil should be kept absolutely clean, for a slight amount of dirt suspended in the oil will act as a grinding compound in the engine. Oil measures and funnels should be carefully cleaned before using.

Kerosene or gasoline should never be used in flushing the oil sump and lubrication system of an engine. Some of the kerosene and gasoline might be retained in the oiling system and dilute the oil when it is placed in the system. A good, light oil is usually satisfactory for flushing the engine.

In the lubrication of push rod ball tips of overhead valve action, a grease must be used which is free from soap, fillers, or acid. Three or four drops of medium machine oil is sufficient in the rear holes of Scintilla magnetos every twenty hours of service. The magneto front holes should be filled. Care must be used that the magneto is not over-oiled.

Oil leaks should be located and corrected immediately before they develop into serious trouble. During warm-weather operation there must be a maximum amount of ventilation about the oil tank, and during cold-weather operation the oil tank and lines must be protected. In severely cold seasons, it is advisable to lag the oil lines. Caution must be used in filling the oil tank that room is left for the expansion of the oil when heated, and that the vent in the oil tank is not closed.

CHAPTER X

TROUBLE SHOOTING

The art of locating troubles in automotive engines and their accessories has developed to a remarkable degree during the evolution of the automobile industry, and it is extremely fortunate that such has been the case, for without such a development more serious disasters would have resulted in aviation. Although slight troubles in the functioning of an automobile engine may be inconvenient, only in rare cases have they been the direct cause of disaster, whereas the same trouble, even though slight, can compel a pilot to make a forced landing at some spot where such a landing cannot be made without serious consequences.

In the upkeep of the automobile engine it is not required to foresee possible future troubles which may cause engine failure, for we may always resort to being towed to the nearest garage, but such an attitude cannot be taken by the airplane pilot or the mechanic in charge, or dire consequences follow. Those mechanics who are responsible to a certain degree for the performance of a plane in the air as well as during ground tests must be able to recognize approaching trouble and by proper maintenance forestall engine failure in the air. To possess such an ability calls primarily for an intimate knowledge of possible troubles and so to service an engine and its accessories that troubles are prevented from occurring.

It has been said that *trouble-shooters* fit to bear such a title are born, not made. This statement is about half true, for although native endowment in reasoning powers is a factor of importance which cannot be overestimated, it is only when reasoning powers are coupled with practical experience and acquaintance with principles involved that we find a man mentally fit to be trusted in the position of trouble-shooter in the field of aviation.

The future success of commercial aviation does not depend solely upon engineering achievements, but to a large degree will hinge upon the caliber of future pilots and *ground men*. It will be but a question of detecting natural aptitude for such work among the rising generation in order to keep the ranks supplied with men of exceptional ability. It has previously been pointed out that careless servicing and lack of

ability to foresee possible troubles and prevent their occurrence may lead to no small inconvenience and expense in the automobile industry. Yet it should be quite clear that a parallel situation cannot be tolerated in aviation. Perfection can be the only ideal to strive for when the lives of pilots and passengers and costly equipment depend upon those men whose task it is to keep a plane in the air.

It will be the duty of supervisors to discriminate closely between men with mechanical ability and men with mechanical ability coupled with superior intelligence; and a careless attitude and habitual knack of forgetting are not included in the mental make-up of what we term superior intelligence. Trouble-shooters, as well as all employed in the maintenance of airplanes, must primarily be thinkers; not merely intelligent workmen who can carry out a task allotted to them, but men of keen intellect, imaginative, resourceful, enthusiastic, and above all wholly conscious of the importance of their work. With such requirements fulfilled, the necessary technical knowledge may be imparted to such minds in a short time with the result that we have men in keeping with the importance of the positions they are to occupy.

That such men are available we have every reason to believe the past has proved; that such men are rare we feel compelled to admit. Those individuals who aspire to ground work in the field of aviation and who believe that they are mentally equipped to meet the demands which will be made in the future, yet at present are not technically trained, should not hesitate in starting some systematic study of aerodynamics and engines as employed in aerial navigation.

To be a master in diagnosing aircraft engine problems there are two qualifications necessary, an intimate knowledge of the mechanism and the faculty of thinking deeply. Of the two qualifications, the latter will serve its possessor better, for experience has proved that it is not always the workman closely associated with a combination of mechanical devices that finds the trouble quickly. The workman who thinks clearly and systematically and admits that he is not certain usually accomplishes more than the one conceited enough to believe his knowledge will guide him instantly to the seat of the trouble.

A thorough understanding of various units is essential, but when a combination of troubles arises, deep thinking becomes an asset that will accomplish the more. The mistake made by most trouble-shooters is hastily jumping to a conclusion from the effects resulting from the cause. For example, an engine performing with every indication that carburetor trouble is present may have ignition disorder instead.

No better example of this can be cited than one which has happened to innumerable trouble-shooters, who after spending hours upon a

carburetor in an effort to stop *popping back* through the carburetor, from a supposedly lean mixture, find in the end that the wires leading from the distributor to the spark plugs are not according to the firing order of the engine.

The foregoing example, though amusing to the skilled workman, is a pitfall many have fallen into and results from the fault of taking too much for granted. The simple disarrangements are frequently the most difficult to discover because one is likely to be misled by the effects produced. It is a well-known fact that carburetors owing to their sensitiveness, which causes them to reflect other engine troubles, are blamed for numerous troubles they are not guilty of. For instance, a sticking inlet valve or numerous ignition troubles will cause an engine to behave in a manner that indicates the carburetor is at fault.

It is not the writer's intention to point out or summarize all the possible troubles and their effects. Such lists are available from many sources dealing with the elementary side of the question of trouble-shooting. It is the practical application of knowledge and unusual complications that will be adhered to in an effort to guide the workman into a better use of his knowledge.

NECESSARY CONDITIONS IN ENGINE

One of the most common troubles met with in aircraft work is the failure of an engine to start. Ordinarily this situation is not difficult to overcome even by the average mechanic, yet in some cases it may prove to be baffling.

It is well known, but often forgotten, that there are five necessary conditions in an engine for it to start and continue running. There are three primary conditions which must be correct before an engine will start and run, namely: **good compression, proper carburetion,** and **good ignition correctly timed.** Close to these conditions is the fourth, **lubrication,** and the fifth, of lesser importance yet necessary for continued running, **radiation.**

The five conditions are not only necessary to start and run an engine, but upon these five conditions and their disorders most trouble-shooting is based. The order in which the conditions are given is the order of their importance. Compression is not only necessary, but there must be good compression. Any cylinder that is without compression for any reason will have no suction unless the cause of there being no compression is due to the inlet valve not seating. In this case the suction may be good through the open inlet valve yet compression be absent during compression stroke if the inlet valve does not

seat properly. Poor compression due to improperly seating exhaust valve, worn or broken piston rings, or leaky cylinder head gasket, will cause a corresponding decrease in suction.

It is obvious that the fourth condition, lubrication, might be the cause of poor compression, therefore becoming closely allied with the condition, compression. The very term *lubrication* means correct oiling of all parts, and merely the fact that oil is reaching the pistons and cylinder walls is no indication that the piston rings are being properly sealed against excessive compression losses.

Without compression in any particular cylinder of an engine no suction will exist to draw in a charge of gas, no matter how perfectly the carburetor is capable of providing a mixture. With a faulty seating inlet valve yet no other leak into the combustion chamber, suction might be good and a charge drawn into the cylinder; yet it would follow that the charge would not be compressed. Therefore, without compression an inducted charge of gas into the cylinder becomes worthless.

With sufficient compression and properly timed valve action to insure good suction, the next logical step to follow is to ascertain whether there is any available gas to compress. Owing to the invisibility of gas in the inlet manifold and the lack of any means which will indicate the proportion of fuel and air passing through the inlet manifold, it becomes difficult to determine whether the cylinders are receiving sufficient charges or are being overcharged.

When suction and compression are found to be sufficient and continued priming of the cylinders fails to bring about any combustion, the ignition should be checked carefully both for quality of spark and the time of its occurrence. A compressed charge of gas of the right proportion is worthless in a cylinder if there are no means to ignite it at the correct time. On the other hand, correctly timed ignition of good qualities is useless if the mixture in the cylinder is too rich or too lean to burn.

When to all appearances and tests, compression, carburetion, and ignition seem to be correct, yet the engine fails to start, the spark plugs should be removed and the engine either turned slowly by hand or left standing to allow the cylinders to dry out thoroughly. If the engine is needed immediately the propeller may be turned backward. The drying out of the cylinders will remove the doubt as to whether an overcharge of gasoline vapor was in the cylinders. The cylinders should then be primed with fresh gasoline in the case of extreme sub-zero climatic conditions. Ether is not recommended by engine manufacturers even as a last resort.

If combustion occurs from the priming but the engine fails to continue

running, it is almost a positive indication that the carburetion is at fault unless it is noted that the ignition fails after a few explosions. Failure of the engine to respond to the priming after a thorough drying out of the cylinders in most cases will prove the ignition or compression, and possibly both, to be at fault. An exception to this could occur when priming with ordinary commercial gasoline if the atmospheric temperature is below zero. Even the use of high-test gasoline will not always provide a gas in the cylinder when the temperature of the cylinder casting is extremely low.

To remove the question of whether the chill of the cylinder is preventing vaporization, hot water should be used in filling the cooling system if the engine is water-cooled. With commercial gasoline being used for priming the point should not be lost sight of that with every degree drop in the temperature of the gasoline less substance in the gasoline is available. The percentage of the liquid fuel that will vaporize depends upon the temperature, and it must not be forgotten that a few drops will not suffice when the thermometer is registering 10 to 20 degrees below zero.

When it is believed that the trouble has been localized to one of the necessary conditions, every effort should be used to make that condition perfect. If every indication points toward ignition trouble yet a correctly timed spark is obtained, the quality of the spark should be suspected. A spark taking place at a spark plug laid upon the cylinder for a test proves little more than the timing. This test does not prove that the intensity of the spark is great enough to jump the gap when under compression, or ignite an inferior mixture of gasoline and air.

If the intensity of the spark at the plug appears to be great enough to the trouble-shooter through experience with that particular ignition system, then the spark plugs should be suspected. It is unusual for all the spark plugs in an engine to fail at the same time. Yet frequently a sufficient number of them may fail to add to the complications. A slight crack in the insulations of several plugs may not have caused them to fail until extreme cold contracted the insulation sufficiently to open the cracks enough to permit leakage of the high-voltage current. A crack in the insulation may not prevent the current jumping the gap at the plug when the plug is tested in the open, yet can prevent the spark occurring at the gap when the resistance at the gap is increased by the compression in the cylinder. A plug with a slight deposit of carbon on the insulation may have its resistance lowered enough to permit leakage of the static charge in the secondary of the ignition coil during the time the breaker contact points are closed, resulting in a feeble spark at the spark-plug gap when the breaker points open.

If no reliable spark plugs are available for a test in the engine, an improvised spark intensifier should be arranged on each spark plug, if none is provided in the distributor, by allowing the wires leading to the plugs to lie a short distance from the plug terminal so the current must jump to reach each plug. The intensified spark resulting from this arrangement has often been sufficient to start an engine when the trouble was due to faulty spark plugs or a weak battery.

With an intense spark correctly timed and at least fair compression any engine will start upon priming with a volatile fuel unless the engine has been primed too much, which is an error easily fallen into during warm weather or with a hot engine, for at high temperatures a few drops may be sufficient to prevent combustion by providing too rich a mixture.

Though difficulties may be experienced in starting an engine when all necessary conditions appear to be correct, it is not a frequent situation. In most cases met with, some one of the conditions necessary is totally and prominently at fault, that is, ignition is either out of time or fails to function at all, or the carburetor does not receive gasoline owing to a clogged fuel supply line or other simple carburetor troubles. These fixed troubles are quickly detected by the average workman by a checking of the three primary conditions necessary.

TROUBLES IN A RUNNING ENGINE

The phase of trouble-shooting that calls for the deepest thinking is troubles arising in a running engine. Whether it is failure to turn up to the maximum speed, a "missing" cylinder, overheating, excessive fuel consumption, or any combination of troubles, the same systematic schedule should be followed. Starting with compression and valve timing, point by point must be checked until the seat of the trouble is found.

Compression that is weak is the cause of more engine troubles than is generally realized. From a view-point of power, compression is of primary importance. Weak compression results in poor suction, which in turn results in a weak charge entering the combustion chamber of any particular cylinder. Poor compression of a weak charge brings about a decrease in power through a drop in expansion pressure during the power stroke. With some valve timings serious overheating will result from the lowered expanding qualities of the exhaust. The lowered efficiency of the engine compels greater throttle opening, thereby bringing about increased fuel consumption.

When the term *good compression* is used, it refers to the correct compression intended for an engine, whether low or high. To be

exacting in trouble-shooting, the correct compression in pounds should be learned. Air-cooled engines in some instances have a lower compression than water-cooled engines, owing to the difficulty in cooling some types of engines by air direct upon the cylinder when high compression is used.

When reliable information is not available regarding the correct compression a fair test may be given to each cylinder by use of a gage screwed into the spark-plug hole and by observing the drop of pressure on the gage after the engine has been cranked with a wide open throttle and stopped at top center at the end of the compression stroke.

It is but fair to the engine to warm it up thoroughly to insure proper fit of the pistons before testing the compression. An engine having aluminum pistons, when cold will have a great loss of compression, yet may have good compression when pistons have expanded to fit the cylinders snugly. On the other hand, an engine with cast-iron pistons that fit snugly in a cold engine may show a decided loss of compression when the engine is heated, owing to a heavy-bodied oil being used in the engine which sealed the pistons when cold and thinned when heated. The character of the oil used must therefore be considered.

On an engine showing 80-lb. compression or higher, a drop can be expected in most cases soon after the piston has been stopped at top center, but this drop should not be too rapid. In many cases a rapid drop will take place down to 40 or 50 lb., after which the gage will stand still, proving that the fit of the pistons and piston rings and the valves will hold the low compression yet is unable to hold the high compression. This rapid fall is an indication that the cylinder walls and pistons or the piston rings and valves are in poor condition. If a prominent leak results from 80-lb. compression, then expansion pressure cannot be expected to be retained wholly in the combustion chamber, for at the time of combustion the pressure will be three or four times as great as compression pressure, therefore, more likely to force its way by the points of leakage.

The importance of correct compression cannot be overemphasized. Two engines of the same size and make yet varying in power and revolutions will be found to have different compressions, owing to superior piston and piston ring fitting in the engine performing the more efficiently.

If the cylinder walls, pistons, piston rings, and valves are in need of attention or replacement, the engine has been in use longer than it is advisable and nothing short of an overhaul will correct the faults.

When the wear of the cylinders and pistons is equal in all cylinders, it is more likely to deceive the trouble-shooter than when some of the

cylinders have been subjected to less wear than the others. With the wear uniform in all of the cylinders the engine will run smoothly, whereas uneven wear, creating weak compression in some cylinders, will set up vibration and cause the engine to perform poorly under all conditions.

It is obvious, therefore, that the compression must be correct if the highest possible efficiency at high speeds is expected. Aside from weak compression affecting the power of an engine, weak compression in but one cylinder will upset the balance an engine has and cause excessive vibration. The lowered compression in one cylinder causes poor induction during the suction stroke, and under certain carburetion conditions may draw in a charge too weak to ignite at certain engine speeds, causing that particular cylinder to misfire and lead the trouble-shooter to suspect the ignition.

COMPLICATION OF TROUBLES

The most discouraging predicament for a trouble-shooter is a complication of troubles, especially when the troubles do not stay "fixed" but occur periodically. When a trouble persists, a close systematic checking will disclose the fault, but to search for a cause of trouble that vanishes when a search is started is a situation calling for the closest application of knowledge combined with the process of elimination.

If an engine "stalls" frequently or misfires after every possible adjustment has been tried, or performs poorly in any way yet every unit functions perfectly when tested, there remains but one method to locate the trouble, and that is the replacing of each unit at a time, thereby eliminating the possibility of that unit being at fault. A carburetor which has been functioning correctly on another engine of the same model should supplant the one suspected. If the trouble occurs again, the ignition system should be replaced. Where a magneto is used for ignition, another magneto should be installed, and if a battery system is used for ignition, the ignition coil, distributor head, breaker assembly, wires and condenser should be replaced entirely or one at a time.

Loose internal connections in an ignition coil can create an exasperating trouble by causing an open circuit when the coil is subjected to vibration from shocks received while the plane is taking off on a rough field, and though an unusual trouble, it is a possible one which must be considered.

A defective condenser may likewise give trouble only when jarred or after a high temperature is reached under the engine cowling. Where the condenser is built in the ignition coil, the entire coil must be changed, but where the condenser is external of the coil, it may readily be changed

for another. A distributor head of composition may have a flaw that permits the leakage of the high-tension current at certain temperatures or at a time when there is considerable humidity in the air.

It is at such times as these that the workman should doubt everything and be willing to try anything in an effort to locate the trouble quickly. Many trouble-shooters waste little time when they recognize the trouble as an unusual one. The gasoline is drained by them from the supply tank, the fuel supply line cleaned, and fresh gasoline used in filling the tank. The carburetor receives the same cleaning, followed by a polishing of the breaker contact points, cleaning of the distributor, and replacing of the spark plugs with a set previously tested out in another engine. Adjustment of the valve tappet clearances, a tightening of all inlet manifold nuts, a search for loose connections, leaky valve guides, or weak valve springs are among the things quickly and easily checked by the trouble-shooter.

A systematic checking of such points as are fitting with a particular type of engine and its peculiarities often saves time in the end, and though the true trouble may not be determined, the workman at least saves the time spent in trying to localize the trouble which may have been a difficult complication of troubles. Following such a system, while not proving the workman to be a master at locating trouble, will, however, reach the desired end, and in many cases it will be the system a highly skilled trouble-shooter will resort to before locating the trouble when the fault lies in a combination of troubles.

UNUSUAL TROUBLES

Lists of common troubles, symptoms, and remedies are available in many elementary instruction books and should be studied by every student of the internal-combustion engine until he is familiar with the symptoms and the remedies; and in his daily work with engines he should likewise endeavor to imagine new possible troubles that might arise from improper workmanship or from "tinkering."

The following list of possible troubles is set down as an addition to the common troubles; though unusual, they are troubles which have been found to be the true cause of improper performance when the usual tests failed. Some of the troubles are directly the result of "tinkering" on the part of an owner or an unskilled workman.

Dent in gasoline supply line.
Carburetor float rubbing on bowl.
Reversed venturi tube.
Abnormally small gasoline supply pipe.

Blow hole in inlet manifold.
Blind gasket on inlet manifold.
Low-grade gasoline.
Excess heat application to carburetor.
Insufficient heat application to carburetor.
Leaky inlet valve guides.
Weak exhaust or inlet valve springs.
Leaky secondary ignition cables.
Flaw in ignition distributor head.
Soldered connections in secondary of ignition circuit.
Oxidized ignition breaker contact points.
High resistance in primary circuit of ignition system.
Resistance unit shorted out of the circuit.
Magneto safety gap too close.
Weak spring tension on breaker mechanism.
Magneto armature striking pole pieces.
Magneto armature out of time with breaker contacts.
Magneto armature out of time with distributor.
Loose internal connections in magneto armature.
Blow hole in cylinder casting.
Blow hole in piston head.
Rough distributor or segments low or high.
Improperly grounded magneto.
Short or open circuit only at high temperatures.
Warped cylinder block.
Over-radiation in cold weather.
Worn bushing on ignition distributor shaft.
New spark plugs which are defective.
Ignition condenser failing occasionally.

He who aspires to qualify as an expert trouble-shooter should realize that it is only by experience and close study that near perfection is reached. Those who are daily associated with engine work have the advantage of being able to put into practice before it is forgotten the knowledge gained by study. A mystery solved each day or each week will soon give greater confidence to face new problems. Details should be mastered, for they are of the greatest importance in aircraft work.

There can be no doubt as to the value of practical experience for those who aspire to become trouble-shooters, and, at best, printed instructions serve merely as suggestions. Not every problem confronting the trouble-shooter may bear a resemblance to troubles itemized in printed instructions, and, unless one has an exceptional memory, itemized troubles are not as firmly fixed in the mind as are troubles located in actual practice.

Next to actual experience at trouble-shooting, the relating of unusual

cases, it is believed, makes a more lasting impression than endless lists of possible troubles. The following cases cited are set down in the hope that they show the many pitfalls that await the careless thinker.

CASE 1

The pilot of a plane powered with an eight-cylinder water-cooled engine reported that an unusual pound had developed in the engine during a cross-country flight, while flying against a twenty-five-mile wind. A test pilot at the base, after a few circles of the field, agreed with the first pilot that a pronounced pound was present when the tachometer registered 1700 revolutions in the air. The engine had been in service but a short time, and had received a great deal of care. A thorough checking of the bearings failed to disclose any at fault, and a consultation of those who were considered qualified to pass judgment resulted in an agreement that one or more of the cylinder blocks was warped. A rumor had been circulated that some of this make of engines had been put out with "green" blocks, which when thoroughly heated would not contract perfectly when cooling after a high temperature. New blocks were available, and without delay the condemned blocks were removed, and new ones fitted in their place. The engine was "run in" for a day, and as everything was apparently in perfect order, a test flight was made. When 1700 revolutions were exceeded, the old pound was still present and with the same intensity.

A new mind upon the job, with no thought of warped cylinder blocks, checked the magneto timing and found it to be 15 degrees too early A search among the records furnished the information that there had been an occasion to remove the magneto during some work on the engine just prior to the flight during which the pound had developed. A hurried timing of the magneto had resulted in a mistiming. The magneto was correctly timed, and a test flight proved that the pound had been caused by the extremely early ignition.

CASE 2

A situation similar to Case 1 was found in a comparatively new engine when a pronounced knock was diagnosed, by reputable mechanics, as a loose connecting rod. The engine was removed from the fuselage and completely torn down. The bearings received careful attention, the fit of the pistons in the barrels was checked, and no effort was spared to locate the seat of the knock. The engine was assembled, the timing of the valves and ignition checked, after which the engine

was set up on a block for a running test. The same knock was present, and it was extremely sharp. Stethoscopes of every variety were brought into use, and after a great deal of concentration upon the problem a mechanic isolated the knock to one section of the engine.

The engine was stopped, and two or three of the valve tappets were removed from that section of the engine where the knock had been isolated. Upon examination of the cam followers, a roller was found having a deep groove chipped across the surface in contact with the cam, caused by a flaw or by improper case hardening.

CASE 3

A certain engine was performing erratically, after a top overhaul, when the spark was advanced more than half way. A capable mechanic spent most of a day adjusting the carburetor, checking valve tappet clearance, spark-plug gaps, and searching for the seat of the trouble in every place he could think of or anyone suggested. The engine performed normally upon all throttle openings as long as the spark was not advanced more than half way.

Time and again the timing of the magneto was checked, but always found correctly timed. Everyone who was qualified was consulted by the mechanic. Many attempted to locate the unusual trouble, but not until a check-up was made upon the work which had recently been done on the engine was a clue discovered. The records showed that after the last flight the breaker of the magneto had been removed for cleaning and adjusting of the breaker points. The mechanic who had been detailed to this job was away on leave of absence; so it was decided to remove the breaker to ascertain whether the absent mechanic had harmed the breaker in replacing it.

An examination brought about the discovery that the mechanic had removed the small key which held the breaker in time with the magneto armature, and had, through carelessness, replaced the breaker in an advanced position relative to the armature, resulting in the armature being in a more favorable position in the magnetic field on retard spark but in an unfavorable position in the magnetic field on advanced spark. The reduced intensity of the spark at the plugs when the magneto was in the advanced position had been the cause of the erratic action of the engine when the spark was advanced.

CASE 4

The inadvisable practice in some poorly managed shops of having one mechanic finish what another has started can well be illustrated in

the following: A mechanic was taken from a job hurriedly and sent away from the field to the assistance of a pilot who had experienced a forced landing. His job fell to another mechanic, who, when relieving the first one, received the information that the engine was popping-back through the carburetor.

An examination of the shop card read: "Tune up engine." It was natural for the mechanic who undertook the job to believe the popping-back was the reason for the order on the shop card. Six hours later the mechanic was still at work, and the engine was still popping-back. The carburetor had been removed several times for the trying of various jets and the changing of the gasoline level. The ignition coil was substituted for another, and the usual routine of trouble-shooting by the process of elimination was followed.

Toward evening after a day of discouraging work the mechanic who had started the job returned and informed the second mechanic that the engine had not been popping-back when the "ship" came in, but had started popping-back immediately after the spark plugs were cleaned. The clue lay there, for it was quickly seen that in replacing the wires leading to the first and second cylinders the wires had been reversed by mistake, caused by both wires protruding from a single opening in the tubing carrying the wires.

It was the work of a few seconds to connect the wires correctly, but a few hours more were required to learn what jets were originally used in the carburetor which by now was badly out of adjustment.

CASE 5

To have a "ship" brought into the shop for the ignition to be checked for a "miss" and be unable to turn out the job through inability to start the engine again was the exasperating situation once caused by "too many mechanics."

In an effort to complete the job in the shortest possible time, one man removed the magneto for examination while another cleaned the spark plugs and assisted a third in replacing oil-soaked wires with new ones. When the magneto was again installed and timed, an unsuccessful attempt was made to start the engine. The magneto was instantly blamed, as it delivered no spark. The magneto was removed and taken apart. The windings of the magneto were tested as well as the condenser. It was suggested that the magnets had been removed and that one had been reversed in the replacing of them, a suggestion which brought a laugh, for the magneto was an inductor type of a design which made it mechanically impossible to reverse the magnets.

Hours passed before an inquisitive mechanic asked of the one who had first removed the magneto what work he had done upon it. It finally was brought to light that the magnets had been weak and the mechanic had recharged them. The inquisitive mechanic found a compass and placing it close to the pair of magnets proved the polarity of one magnet was reversed in the charging.

While it was not possible to reverse the magnets mechanically, it was possible to reverse them magnetically, and this had been done through carelessness.

CASE 6

A trouble making its appearance periodically and keeping in hiding when a search is made for it is probably the most difficult task for a trouble-shooter. A new engine failed in a "ship," and a forced landing was made. A complete checking failed to disclose any trouble, and the incident was credited to water in the gasoline. Two days later the engine again failed on a take-off, and a crash was narrowly averted by the pilot. Again the engine was checked and a thorough ground test made without any fault being discovered. The ship was once more flown, but remained over the field, and after a flight of half an hour the engine stopped and a dead stick landing was made. A mechanic reached the plane and on removing the engine cowling detected the carburetor float chamber filling up slowly. The carburetor and gasoline line were removed, and at the point where the gasoline line reached the carburetor bowl a rubber band was found.

In some way, through negligence, the rubber band had found its way into the gasoline tank during the process of fueling, and for days had been working through the gasoline line. It was evident that at times the rubber band became lodged at some bend in the pipe in such a manner as to stop the flow of gasoline, only to straighten out again and permit gasoline to flow sufficiently to deceive the mechanic who had checked the flow from the line.

CASE 7

An occasional "skip" that developed into a frequent one only when a "ship" was taking off was a trouble of long standing. Once the ground was left the "miss" vanished, and did not occur again until another take-off.

Everything about the engine was checked. Another carburetor was tried. The wiring of the ignition was changed for new. A set of spark plugs that had worked well in another engine of the same make and model was also used for a test. The compression was very good and

also uniform in all the cylinders. The valves had been ground in carefully, the spring tensions checked, and the clearance at the tappets correctly adjusted. The cylinders, during a thorough examination when the engine had been apart, were examined for possible blow holes in the casting, which might be letting water into the combustion chamber. The ignition coil and the condenser were tested time and again in the shop, and the end of places to seek the trouble had been reached.

A mechanic riding with the pilot detected that the "miss" was more pronounced when taking off on rough sections of the flying field, and, suspecting that the jarring had something to do with the missing, replaced the ignition coil with a new one. The "miss" disappeared with the new installation, but returned when the old one was again used.

An internal loose connection in the ignition coil had been the cause of the exasperating trouble, and though the coil had stood up well under every shop test, the shop test had not included shocks, the actual condition which the coil had to work under when the rough flying field was crossed.

CASE 8

A pilot reported his inability to maintain wide open throttle owing to repeated "cutting out" of the engine when he opened the throttle to the maximum position. The usual routine of checking was made on the engine, carburetor, fuel supply, and ignition. A test flight showed no improvement over a long test, though for short periods the engine functioned satisfactorily.

The fuel tanks were given a thorough cleaning, and the fuel lines were inspected for obstructions. Another carburetor was tried, another magneto was installed, new wires throughout were attached, and new spark plugs were used which had been tried out in another engine of the same make and model.

The engine continued to "cut out," and the problem became a serious and costly one, for no small amount of time was being consumed in an effort to locate the trouble. Every indication pointed toward the carburetor's being starved at times, and though the fuel line had been inspected time and again, it was again removed. At one point in the line a piece of hose had been in use, and a closer examination of this hose disclosed that the inner rubber lining had been eaten away by the gasoline, exposing the fabric of the hose. A loose piece of this fabric was being lifted by the passage of gasoline, and acting as a flapper valve when the flow increased under wide open throttle conditions and the accompanying vibrations, caused a momentary starving of the carburetor, resulting in the "cutting out" of the engine.

CASE 9

During a cross-country flight an engine began "missing" and "cutting out," and as the pilot was aware that he was low on fuel, he brought the "ship" into the nearest airport, where he refueled. A ground test developed no "missing" or "cutting out," and the pilot took-off for his destination. After a half hour the engine again began "cutting out," and only after a long hard fight was the pilot able to bring the "ship" to another landing field.

The usual inspection was made and resulted in some water and dirt being found in the carburetor. The fuel tanks were cleaned out and replenished, and a ground test indicated that everything was all right.

Again the pilot took to the air, and after an hour of flying the engine started "cutting out" again and continued giving considerable trouble until the destination was reached.

A careful check was made of everything, resulting in no disorders being found. Another flight for a test brought the same trouble about. Another magneto was obtained for a trial, and the trouble vanished. A bench test of the magneto failed to disclose any fault, but when the temperature of the magneto was raised by placing a blow torch near it during the test, the condition was duplicated under which the magneto had to work in flight, and the magneto failed. An examination brought to light that the condenser was failing after a certain temperature was reached under the cowling, which accounted for the magneto's perfect behavior when the temperature was low.

CASE 10

A similar situation to Case 9 occurred with a "ship" which for a week was not able to get away from the field. The engine had failed one day after twenty minutes in the air, but, as the field was near, a dead stick landing was made. Everything was checked, and a test was made above the airport. At the end of twenty minutes the engine failed, and another dead stick landing was made. No matter how carefully everything was checked, twenty minutes of flying resulted in the failing of the engine.

The ignition was carefully gone over, but as it was a battery system, another complete system was not on hand at the field. After a week of failure, another distributor head was obtained, and a test flight with the new distributor head brought about perfect performance.

The composition head had undoubtedly had sufficient resistance at low temperatures, but a hidden flaw opened up at higher temperatures, resulting in the lowering of the resistance of the head. The high-tension

current found an easier path through the flaw and resulted in the failing of the engine through the lack of ignition.

The foregoing cases should be ample proof that in trouble-shooting the things that will carry one the farthest are deep thinking, a study of details, and an attitude of taking nothing for granted. The little things count! In particular, details were never more important than they are to the man whose lot it is to service an aircraft engine. He should never cease being a student. He should constantly be in search of information. In his notes and files should be found correct, up-to-the-minute data of every new development or change in ignition systems and carburetors, for it is only through such application to his problems that he can hope to be successful over a long period of time.

It is not practicable to compile data concerning every clearance allowed on crankshaft bearings, pistons and piston pins, valve tappets, etc., of every engine, for such information, if published in book form, would quickly become obsolete. The aviation mechanic usually specializes on two or three makes of engines, and it is his duty to apply himself closely to the study of these makes. For these makes he is required to be alert in regard to all changes in various bearing clearances the manufacturer may suggest from time to time. The instruction books accompanying any particular engine apply solely to that engine, and any supplement to that instruction book should be from no other source than the engine manufacturer.

CHAPTER XI

THE PRATT & WHITNEY HORNET ENGINE *

The following description of the Pratt & Whitney Hornet Engine is given as a typical example of a high-powered, new production engine to which the theory in this treatise may be applied.

The Pratt & Whitney Hornet Engine has nine radial air-cooled cylinders of $6\frac{1}{8}$-in. bore and $6\frac{3}{8}$-in. stroke, and is rated 525 h.p. at 1900 r.p.m. The rating of the individual engine is given on the engine nameplate.

The unique features of this engine are its solid master connecting rod and two-piece crankshaft, the forged aluminum crankcase, enclosed valve gear, built-in supercharger, and the grouping of all accessories at the rear. These major features, combined with painstaking manufacture, make possible the Hornet's dependability and a high performance for the airplane with which it is equipped.

In these instructions the following definitions will be used:

The propeller end of the engine will be called the front and the accessory end the rear. The direction of rotation of the crankshaft is anti-clockwise when viewed from the propeller. The cylinders are numbered consecutively in the direction of rotation, beginning with the top cylinder, which is called No. 1. The right and left sides of the engine will be referred to as viewed from the rear.

SPECIFICATIONS

Model.—R–1690–A–1.

Rating.—Rated power (anti-knock fuel) 525 h.p.

Rated Speed.—1900 r.p.m.

Valves.—Number per cylinder, 2; material (inlet), silchrome; material (exhaust) CNS; lift (inlet), $\frac{11}{16}$ in.; lift (exhaust), $\frac{9}{16}$ in.; diameter inlet port, $2\frac{1}{2}$ in; diameter exhaust port, $2\frac{1}{2}$ in.

Valve Timing.– Inlet opens, 10° early; inlet closes, 60° late; exhaust opens, 71° early; exhaust closes, 31° late.

Over-All Dimensions.- Outside diameter, $55\frac{7}{16}$ in ; mounting bolt circle diameter, $23\frac{3}{8}$ in.; total length, $44\frac{7}{8}$ in; length back of mounting, $14\frac{1}{4}$ in.; distance from mounting to C. L. of propeller, No. 1 blade end, $25\frac{31}{32}$ in., No. $1\frac{1}{2}$ blade end, $26\frac{1}{32}$ in., No. 2 blade end, $26\frac{9}{32}$ in.

* The data in this section are presented through the courtesy of The Pratt & Whitney Aircraft Co.

Master Rod.—Type, one-piece; form of shank, I-section.
Link Rods.—Form, I-section.
Cylinders.—Barrel, steel; head, aluminum; cooling fins, integral.
Valve Springs.—Number per valve, 2; form, helical.

Fig 87 —Three-quarter Front View of the Hornet Series A-1.

Oil Pump.—Type, gear; number of sections, 2; oil pressure, 75–100 lb.
Crankcase.—Material, aluminum; number of sections, 5
Crankshaft.—Type, single-throw, two-piece; main bearings, ball or roller; thrust bearing, ball type.

General Form.—Cylinder arrangement, radial; number of cylinders, 9; cooling, air; bore, 6.125 in.; stroke, 6.375 in.; piston displacement, 1690 cu. in.; compression ratio, 5.00 : 1.

Magnetos.—Make, Scintilla; number, 2; type, VAG9–D; timing (full advanced), 30°; direction of rotation, clockwise.

Spark Plugs.—Type, B. G. Hornet No. 4; thread 18 m/m.

Tachometer Drive.—Type, A. S. Standard; number, 2; rotation, counter-clockwise speed, ½ crankshaft.

Supercharger.—Make, General Electric; type, centrifugal.

Carburetor.—Make, Stromberg; type, NAY–7–B; number of barrels, 2.

Carburetor Setting.—The test log sheet shipped with each engine gives details of jet and choke sizes for the individual engine.

Weight.—Weight of Hornet, with magnetos and carburetor, but no extras, 780 lb.

CONSTRUCTION

Crankcase. *The Main Crankcase* is divided into two similar sections in the plane of the cylinders and united by nine through bolts between the cylinders, as well as by the cylinder flanges. With this construction the explosion forces are equally distributed between the two main bearings, one of which is carried in each section of the case.

The Nose, or front section of the case, is a hemispherical aluminum forging. It carries a deep row ball bearing which transmits the thrust of the propeller from the shaft to the engine mounting via the crankcase. The valve tappets are also carried in this section, which encloses the cams and their operating mechanism.

The Blower or mounting section supports the engine in the airplane and is attached to the rear of the main case. The supercharger is carried in this section, together with its gearing. The mixture is fed into an annulus from the impeller and thence to the cylinders by means of tangential pipes. See Fig. 72.

The Rear or Accessory Section of the case is attached to the blower section. It carries all the accessories, including two Scintilla magnetos, an Eclipse momentum starter, fuel pump, double Stromberg carburetor, oil pumps, strainer, oil pressure relief valve, tachometer drive, and two gun synchronizer drives. Provision is also made for mounting and driving a generator. See Fig. 74.

The Blower and Rear Sections of the case form an assembly and may be removed from the main case as a unit, without disturbing any of the accessories or their gearing. Likewise, the main and nose sections may be removed as a unit with the cylinders in place, leaving the blower and rear sections in the airplane.

Crankshaft.—*The Single Throw*, two-piece crankshaft is supported on three bearings. There is one roller bearing on each side of the crank-

pin, and the third, a ball bearing, just behind the propeller hub, takes the propeller thrust as well as radial load. To assemble the single-piece master rod the shaft is divided into a forward and rear section. The crankpin is integral with the forward section which transmits the power to the propellor hub carried by it. The rear section telescopes into the crankpin, and is carried completely through it. The two sections are united by a through bolt and kept in the proper angular relation by splines.

Connecting Rods.—*The Master Connecting Rod* has a solid instead of detachable cap big end. This construction makes possible high crank speeds which have been impossible with the two-piece rod. Bronze-lined big end bushings are inserted in the rod and bear directly on the crankpin. Eight I-section link rods are attached to the master rod by means of knuckle pins. Each rod is bronze bushed for the piston and knuckle pins. Oil is carried under pressure to the big end bearing, and also to the knuckle pins. See Fig. 79.

Cylinders.—*The Cylinder Barrels* have integral fins and are machined from steel forgings. Each barrel is screwed and shrunk into a cast aluminum cylinder head. This is a permanent joint and cannot be disassembled. Each cylinder has one inlet and one exhaust valve, seating on inserts which are shrunk into the head casting.

The proper cooling of the exhaust valve seat and stem is of great importance, especially in an air-cooled engine. The Pratt & Whitney engine has the valve gear housed in extensions cast on the cylinder head. These parts form additional radiating surface, and the one on the exhaust side is provided with cooling fins. As a result of this construction, valve grinding is not necessary oftener than every 200 to 300 hours of service.

Valve Mechanism.—All valve operating parts are enclosed. The rocker arms are supported by ball bearings in the rocker housings which are part of the cylinder head. The eighteen tappets are located in the front section of the crankcase and actuate the rocker arms through tubular duralumin push rods which have hardened steel ball ends. These rods are enclosed by telescopic covers held in place by springs. The cover tubes can be collapsed by hand, and bayonet locks are provided to retain them in this condition while they are being removed. Each rocker housing has a removable cover held in place by a spring bail. These covers and the push rod covers and push rods can be removed without special tools.

Two concentric valve springs are used, secured to the valve stem by a split cone and washer. Inlet and exhaust valve springs are interchangeable. The valve springs can be removed without taking out the

rocker arms. After the push rod is taken out, the rocker arm can be tipped up far enough to allow the valve springs to pass. The valve clearance adjusting screw is in the end of the rocker arm over the valve. A half ball is used between the adjusting screw and the valve stem to minimize friction at this point.

Timing Gear.—The cams, which actuate all the valves, run on a sleeve on the crankshaft. A train of spur and internal gears drive the cams at $\frac{1}{8}$ crankshaft speed in the opposite direction to the crankshaft rotation. The cam drive gear on the crankshaft is not keyed to the crankshaft, but to the sleeve on which the cam itself rotates. The front end of this sleeve has a large number of serrations which mesh with similar serrations on the rear end of a sleeve which carries the propeller thrust bearing. These two sets of teeth are normally held tightly together by the thrust bearing nut. When the engine is being timed, however, this nut is slacked off, the two sleeves are slightly separated, and the cam can then be turned by a special wrench which has teeth to engage with one of the cam drive gears. After the adjustment is made it is locked by screwing up the propeller thrust bearing nut.

Accessory Drives.—The accessories are driven by three lay shafts which extend entirely through the blower and rear sections. Each shaft carries a spur gear at its forward end, which engages with a gear attached to the rear of the crankshaft. The upper shaft provides a drive for the momentum starter and a generator if used. Each of the two lower shafts drives a magneto at its rear end, through a readily adjustable coupling. Besides this, two vertical drives are provided for by a bevel gear on each shaft. The upper drives are for two gun synchronizers and two tachometers; the lower drives an oil pump on the right side and a fuel pump on the left.

The supercharger impeller shaft is in line with the crankshaft and driven from it at high speed by two pairs of spur gears. A clutch is provided to take care of rapid acceleration. See Fig. 74.

Lubricating System.—The oil pump assembly consists of two gear pumps, one supplying oil under pressure to the engine bearings, and the other for scavenging. Oil is taken from the tank by the pressure pump, and after passing through a strainer located just forward of the carburetor is carried through the blower section, down into the sump and thence up into the hub of the cam drum in the nose of the engine where it is fed into the crankshaft. A relief valve to regulate the oil pressure is located beyond the oil screen just off the strainer chamber. The crankpin bearing, knuckle pins, cam drum, cam drum pinion shaft, accessory shafts, and the supercharger gearing are all lubricated by oil under pressure. Oil is taken from the strainer chamber by drilled

passages to lubricate the accessory drives. All the other engine parts are provided for by the mist or spray from the pressure oiled parts except the rocker arms and the magnetos. The surplus oil drains into a sump carried between cylinders No. 5 and No. 6, from which it is returned to the oil tank by the scavenging pump. The discharge or warm oil is carried in a jacket around the carburetor elbow to prevent the throttles freezing. See Fig. 83.

There is an external Zerk nipple on each valve rocker housing, and lubricant applied here supplies the rocker bearings and also reaches the push rod socket through a hole drilled in the rocker. There is also a similar nipple in each valve adjusting screw, to lubricate the half ball which bears on the valve stem.

Intake System.—A double-barreled Stromberg carburetor is used. The engine has provision for driving a C-3 or C-5 Air Service type fuel pump, which can be supplied with both an integral pressure-regulating valve and by-pass valve for the hand pump. The mixture is taken from the carburetor and delivered to the cylinders by means of a General Electric centrifugal supercharger. The fuel pump, carburetor, and supercharger are located at the rear of the engine. A mixture control is provided which is effective to 25,000 ft.

Ignition.—Ignition is furnished by two nine-cylinder Scintilla magnetos located at the rear of the engine, each firing spark plugs in all nine cylinders, thus giving two independent sources of ignition. A Splitdorf hand booster magneto is furnished for starting ignition.

Starting.—An Eclipse hand or electric momentum starter can be furnished. Energy is stored in a small fly wheel running at high speed which furnishes power to start the engine. This equipment is capable of turning the propeller from four to six complete revolutions on one winding.

OPERATION

Propeller.—The propeller must be set so that it will hold the engine to its rated speed at full throttle in level flight near the ground. It has been found in some cases that operators accustomed to slower speed engines have set their propellers in such a way as to restrict the maximum r.p.m. of the engine to considerably less than the rated speed. This is very detrimental and is extremely likely to cause trouble from detonation, etc., since the carburetor setting and valve and ignition timing have all been adjusted for the rated speed. It is equally dangerous to set the propeller to turn more than the rated speed in level flight, and the Pratt & Whitney Company will not be responsible for engines operating under these conditions.

The care and maintenance of propellers is described in the propeller section of this book. The thread on the front of the crankshaft has been changed to agree with the S. A. E. Standard for No. 40 shaft end. This changes the diameter of thread from $2\frac{7}{8}$ in. to $2\frac{13}{16}$ in. The same propeller hub can be used with the Series A-1 and B. The proper front cone and nut must be used.

Fuel.—The best grades of fuel should always be used. Although fuels vary greatly in quality and effect on the engine, the difference in cost between good and bad fuel is a very small part of the total expense of operating the airplane. This difference will be repaid many times in freedom from trouble, increased power and fuel economy. The anti-knock value of fuel is the most important factor in determining its suitability. Although fuel specifications can be used to indicate the general qualities of fuels, unfortunately no method of determining the anti-knock value is available to the average operator. It has been found that gasolines from West Coast crudes have a natural anti-knock value, and Grade B Domestic Aviation gasoline from these crudes is entirely satisfactory for use without doping of any kind.

In all cases we recommend the use of West Coast base gasolines where possible. Some Grade B gasolines from East Coast and mid-continent crudes are satisfactory and some are not. In any case where the anti-knock value is not definitely known, the use of 15 to 20 per cent benzol thoroughly mixed with the gasoline is recommended. The benzol should be of a good grade, free from sulphur, and should conform to U. S. Army Specification 2-58. Tetra ethyl lead may also be used where benzol is not obtainable or where its cost is prohibitive. Three to four cubic centimeters of ethyl fluid per gallon, never more, will be found sufficient. It is very important that the ethyl fluid be thoroughly mixed with the gasoline. The best method of doing this is to stir the ethyl fluid into five gallons of gasoline and then add this mixture to the fuel tank which has already been partly filled. Considerable damage may result from an improper mixture.

Under no circumstances should the engine be operated at or near full throttle on ordinary automobile gasoline. As an emergency measure it is possible to fly a lightly loaded ship at part throttle on this gasoline, but great care should be exercised to see that the power used is kept at an absolute minimum.

In general, a fuel should meet the following specifications: Baumé gravity not heavier than 72°, unless the fuel is derived from West Coast crude, in which case 66°–68° Baumé should be all right. Fifty per cent should distil off at not over 221° F., and the end point should not be over 374° F. A rough and ready method for arriving at the

relative value of different fuels for aircraft use is to compare the temperature at which 50 per cent distils off. The lower the temperature the better the fuel, and these figures will give some indication of the antiknock properties of the various samples. The use of low grade gas will cause uneven distribution and overheating. Damage to the engine is sure to ensue. Furthermore, the fuel consumption in gallons per hour is likely to be considerably less with the higher-grade fuel.

For the operation of engines on the military rating, either Grade A Domestic Aviation gasoline should be used or Grade B with 15 per cent benzol, and in an emergency Grade B with 4 cc. of ethyl fluid per gallon.

Care should be taken to see that the fuel has no water or foreign matter in it, which can be accomplished by straining it through chamois. Precautions of this kind often eliminate forced landings.

Proper Operating Conditions.—Propeller speed, full throttle on the ground, usually 150 to 200 revolutions less than level flight, depending on propeller design.

Propeller speed, level flight—the same as the rated speed of the engine within 50 revolutions, plus or minus. If the propeller is set to allow 1900 r.p.m. at full throttle the engine will operate at a lighter load at any given speed, say 1600, than if the propeller is set for 1850 r.p.m. at full throttle. In other words, it does not favor the engine to hold it down to less than the rated speed at full throttle.

Desired oil outlet temperature, 60° C. or 140° F.
Maximum oil outlet temperature, 75° C. or 170° F.
Desired oil pressure, 75 to 90 lb.
Minimum oil pressure, 60 lb. (From all speeds above 1200 r.p.m.)
Oil consumption, cruising at 1700 r.p.m., between one and two quarts per hour.
Desired (minimum) fuel pressure, 2 lb.
Maximum fuel pressure, 4 lb.

Starting.—Retard the spark one-third, set the mixture control full rich, crack the throttle slightly open, about one-half inch on the quadrant, and turn the ignition switch to the "On" position. Make sure the fuel supply is turned on and pressure pumped up with the hand pump to at least 3 lb.

Close the adjustable nose shutters, insert the starting crank and wind up the starter. There is little danger of cranking the starter too fast. Enough energy should be stored up to crank the engine at least two or three complete revolutions. This takes about a minute, and the starter speed necessary will be learned after one or two trials. When starting stone cold, prime the engine with three or four complete strokes

of the priming pump. Pull the primer plunger back slowly to obtain a full charge and push it in rapidly to atomize the fuel. *Be sure and shut off primer valve, as engine may otherwise be flooded.* When the starter has been wound up, quickly buzz the hand magneto and pull the starter trigger. If everything is in good condition, the engine should start immediately even in cold weather. As soon as the engine starts, advance the spark.

When the engine is warm, two or three strokes of the primer will be enough. *If the engine does not start immediately, do not keep on priming, but find out what is wrong. Excessive priming washes the oil from the cylinder walls, and is very likely to cause scoring of the pistons and cylinders.* The primer fuel supply should be shut off as soon as the engine is primed.

If the engine fails to start, check to see whether the switch is on, the throttle is just cracked open, the mixture control is set full rich and that there is actually fuel at the carburetor and at the primer; also that the starting magneto gives a good spark at the running magneto.

If the starter runs down before the engine starts, the starter jaw will be left in engagement. Before the starter can be rewound, it is necessary to disengage the jaw, either by pushing in the starter trigger or by turning the propeller forward a short distance.

Idling Adjustment.—On a new installation there are two adjustments to be made to obtain proper idling. Mixture regulation for idling is obtained by moving the two small levers on the front side of the carburetor barrels, just under the top flange of the carburetor. These are moved toward each other to richen and farther apart to lean the mixture. The adjustment should be made when the engine is warm and should be as rich as possible and still have good operation while warm.

To adjust the idling *speed*, the set screw in the throttle lever is turned. Slower idling may be permitted with a heavy propeller than with a light one. Do not slow the engine down so much that it is in danger of stalling.

Hard Starting.—An engine in good condition should start promptly regardless of the air temperature, providing the foregoing instructions are carefully followed. Hard starting is often found to be caused by leaky primer lines or primer pump packing. All primer connections should be kept tight and the pump packing properly adjusted. In some installations it is necessary to operate the wobble or hand pump while priming, as otherwise the primer may not receive any fuel. Another frequent cause of hard starting is that a strong spark does not reach the running magnetos from the starting magneto. This can be readily checked by removing the high-tension lead from the hand starting

magneto and trying it on the engine, at the same time turning the starting magneto crank. The spark should jump from $\frac{1}{4}$ to $\frac{3}{8}$ in. without difficulty. If it does not, it is likely that the insulation on the high-tension wire has been damaged, or that a proper ground has not been provided between the hand-starting magneto and the engine.

Better success will be had if the throttle is allowed to remain in a slightly cracked open position after the engine starts rather than to pump it as soon as the engine makes the first explosion, as this practice breaks the suction on the idle jet and makes successful starting more difficult.

Ground Test.—After starting, run the engine slowly, in order to warm it up gradually, until the oil temperature has reached 100° F. or 40° C. After the oil has been warmed up, the engine should be gradually brought up to full throttle. Before doing this, be sure that the wheels are properly blocked and the stick pulled back. With the throttle wide open, try both magnetos with the switch, observe whether the fuel pressure is between 3 and 4 lb. and the oil pressure from 75 to 100 lb.; observe also the propeller speed. For ships equipped with propellers permitting a level flight propeller speed of 1900, the ground speed of the propeller will be between 1500 and 1650 r.p.m., depending upon the type of the propeller used.

Do not operate the engine at full throttle on the ground for more than a moment or two. Continued running under these conditions is unnecessary and will result sometimes in damaging the engine. In some installations the effective part of the propeller blades is so far removed from the crankshaft that insufficient cooling is provided for the engine while the plane is at rest, although the installation may be perfectly satisfactory while in the air.

Open the nose cowling shutters before taking off.

Rough Running.—The usual cause for rough running, providing the ignition is functioning correctly and the carburetor is properly adjusted, is an unbalanced or fluttering propeller. The Pratt & Whitney engine is carefully balanced at the factory and should run very smoothly. If it does not, the propeller should be inspected. First, if it is a metal propeller, the angle of the blades at the same station should be carefully checked on a surface plate with a protractor. Next, it should be balanced on a mandrel and tracked. After this inspection, the blades should be observed for flutter while running at full speed on the ground. This condition may not exist at low engine speeds, but becomes pronounced at full throttle. The substitution of a propeller from another ship which is known to run smoothly will sometimes be found a convenient check of this situation.

Oil Pressure.—Oil pressure should register immediately after starting. If there is no indication on the oil pressure gage after 30 seconds, **stop,** check up the oil supply, and especially the oil suction pipe connections. A very small leak in the oil suction line will prevent the oil pump from working properly. Do not continue running the engine unless oil pressure is obtained. The normal operating pressure is 75 lb. at full speed and at least 25 lb. idling.

Low oil pressure is usually due to an air leak in the line from the oil tank to the pressure pump. For this reason the connections should be carefully checked. Be sure that an adequate amount of hose, at least an inch, overlaps both the pipe and the connection on the engine, in order to have sufficient area for the hose clamp. No adjustment is provided for the oil pressure, as low pressure indicates trouble in the lubricating system which cannot be corrected by a new adjustment of the relief valve. If the connections are tight and the proper kind of oil used and still the pressure is low, it may be due to a loose cam bearing or a loose master rod bearing. These two possibilities are very unlikely, and should be investigated only after all other possible causes have been considered.

Excessive oil consumption and fouling of spark plugs may be due to an air leak in the pipe which takes oil from the sump to the suction pump on the engine. This will prevent proper scavenging of the crankcase. See if the flanged joints have good gaskets and are bolted up tight.

Oil Leaks.—Particular care has been taken in the design and manufacture of the Pratt & Whitney engine to insure its being oil tight. Leakage is an indication of trouble and consequently should be investigated. For this reason it is strongly recommended that the engine be kept clean, so that any oil leakage may be noticed and readily traced to its source.

Mixture Control.—*The mixture control should be kept at " Full Rich " for all flying below* 5000 *ft., especially when landing.* The mixture control should be used *above* 5000 ft., being careful to adjust it so that the maximum r.p.m. is obtained. This can best be done by flying level with the throttle in the fixed position, and observing the tachometer.

Treatment of New Engine.—Careful treatment of a new engine prolongs its life, and is just as necessary as proper driving of a new automobile. Each engine is run approximately 15 hours at the factory before it is shipped, and it is thought that a total of at least 25 hours careful running is desirable. During the first 10 or 15 hours of operation in the plane it is well to warm up the engine gradually after each start, and to stop gradually also, rather than shut off suddenly from full speed. During this period the engine should not be run wide open

any more than absolutely necessary, and sudden acceleration should be avoided. The same precautions apply to some extent at any time during the life of the engine.

As a further aid in running a new engine, it is recommended that a pint of oil be added to each 10 gallons of gasoline for the first 10 hours of operation.

These measures, together with careful attention to maintaining the proper oil pressure and frequent change of oil, will result in polishing all moving parts so that long and trouble-free service will be rendered. *The first 10 hours in service are the most important in an engine's life.*

To Get Best Economy.—When cruising at an engine speed of 1750 r.p.m. or less, it is feasible to burn quite a lean mixture and thus effect a saving in fuel. The mixture which gives the best economy at any given throttle setting is somewhat leaner than the mixture which gives the best power. With a propeller which allows the engine to turn 1900 r.p.m. at full throttle, there is a difference at cruising speeds of about 40 r.p.m. between "best power" and "best economy" for any particular throttle opening. This gives us a ready means of setting the controls to obtain the least possible fuel consumption for any desired speed.

If it is desired to cruise at 1650 r.p.m., for instance, adjust the throttle to obtain 1690 r.p.m. with the mixture control set for the best power or highest revolutions; then lean the mixture down until the speed drops 40 revolutions, or to 1650, leaving the throttle set as before.

Caution: When flying at full throttle, do not attempt to lean the mixture any more than enough to compensate for altitude. Overheating will result from too lean a mixture at full throttle. At speeds between 1850 and 1700 r.p.m. it is all right to run somewhat leaner; the mixture control lever may be set just on the lean side of the position for best revolutions. At 1700 or below, it is generally possible to adjust for the best economy, always remembering to richen up the mixture before doing any maneuvering.

Care must be taken whenever descending to a lower altitude to readjust the mixture control. In general, upon ascending, the mixture should be leaned out; it must be richened as the plane descends. In gliding in for a landing put the mixture control in the full rich position.

COLD-WEATHER OPERATION

Satisfactory engine performance in cold weather and at high altitudes requires a mixture heater. The Pratt & Whitney heater is a universal device which is suitable for all types of ships.

The heater is located between the carburetor and the rear section of

the crankcase. It consists of an exhaust heated section of the intake system. Any fuel which may leave the carburetor in a liquid state is vaporized by the heater before entering the supercharger. Tests have shown that heat applied at this point is much more effective than before the air enters the carburetor.

Cold-weather operation without the heater will cause rough running due to poor distribution. Raw fuel is fed to certain cylinders causing them to run rich, while other cylinders will run too lean. Continued operation under these conditions will result in high fuel consumption and unsatisfactory operation.

This heater provides a means of completely and permanently insulating the hot exhaust pipes inside the cowling. Furthermore, the heated air which serves as the insulating medium can be drawn into the induction system to vaporize the fuel more thoroughly and prevent the carburetor from freezing under abnormal weather conditions. In the main, the air heater as furnished is composed of a heater body, an air scoop and preheating pipes.

The heater body is of cast aluminum with a cast-in steel pipe for the passage of the exhaust gas. The steel pipe prevents the hot gases from eroding the finned aluminum jacket. The pipes which conduct the exhaust gas to and from the heater body slip over the protruding ends of the cast-in tube. To provide for expansion, slip joints should be maintained at these points. The heater body fits between the carburetor and the rear section of the crankcase. It is $6\frac{1}{8}$ in. in overall height, and therefore lowers the carburetor, carburetor controls and piping by the same amount.

A gasket should not be used between the carburetor and heater, as it will interfere with a desirable heat flow to the carburetor in preventing ice formation. Braces are provided for steadying the heater and carburetor assembly. These braces should be attached to the two end studs on the engine side of the carburetor flange and two studs on the crankcase flange.

The air scoop which attaches to the base of the carburetor is also of cast aluminum. It can be cut off below the air control valve to best lend itself to the particular shape of cowling through which it will protrude. A flapper valve is provided in the scoop to regulate the temperature of the air entering the carburetor. When the valve is fully open, very little air passes through the preheater pipes, and conversely, when the valve is closed, the majority of the air takes the path provided for it by these pipes. This valve should be controlled from the pilot's seat and should be closed off no more than is necessary to give smooth engine operation. For the most part, it will not be necessary to take air

through the preheater pipes. However, in certain weather conditions, ice will have a tendency to form around the fuel discharge nozzles in the carburetor. This is a condition to be avoided since it causes the engine to lose power and fall off in speed. The valve control shaft is equipped with a double spring, one end of which serves to return the valve to its original position in case it is forced open to relieve the pressure of back fire in the induction system. The other end maintains a continuous pressure on the valve tending to close it, and in doing so prevents the valve from fluttering in mid position and permits the use of a simple one-way control to the cockpit. Mounting pads for the preheater pipes are provided on both sides and back of the scoop. This is done to make the unit more universal in its adaption. The preheater pipes can be connected to any two pads, the selection of which will be governed by the particular installation.

Special equipment and operating methods are necessary for satisfactory cold-weather operation. Aside from the hot spot mixture heater, an adjustable nose cowling is of importance. The oil tank should be inside the cowling, and in cold weather protected from the slip-stream. In severe climates the oil sump which hangs between the two bottom cylinders of the engine should be lagged with insulating material or shielded. The tank and sump must both have large drains, accessibly located. All oil should be drained from both the tank and sump immediately after a flight, and hot oil put in the tank immediately before the next flight. A lighter engine oil should be used than for warm weather.

To insure correct readings on the engine oil pressure gage, it is well to disconnect the gage pipe at both ends and blow it out clean, and then fill with castor oil and reassemble it. The castor oil will not congeal, and a pressure reading will be obtained as soon as the engine pump begins to function. The engine is fitted with primer nozzles on cylinders 1, 2, and 9, and these must be connected to the primer pump furnished. It may be desirable to feed the primer pump from a small separate tank which can be filled with a 50–50 mixture of ether and high-test gas.

Starting.—Check over the engine while still in the hangar. Prepare for starting as instructed, being sure to shut the adjustable nose cowling, and have the full heat supply turned on to the mixture heater over the carburetor. Fill the tank with hot oil and pull the propeller over two or three times by hand. Then roll the ship outside and wind up the starter to the maximum speed. Experience will tell how much priming is necessary, possibly 5 or 6 strokes. After starting, idle at about 800 r.p.m. until the oil temperature reaches 30° C. or 85° F. Watch the oil pressure and stop immediately if it is not at least 30 lb.

Warm up gradually, opening the throttle as the oil temperature comes up. When the oil temperature reaches 50° C. or 120° F., and the oil pressure is steady at 75 lb., the engine is ready for flight.

When in flight adjust the nose cowling to maintain the oil temperature between 50 and 65° C. or 120 to 150° F.

Unless the plane is kept in a hangar at a temperature of 50° F. or more, drain the oil from the tank and sump after each flight.

PERIODIC INSPECTION

The engine should be checked before every flight and at regular intervals.

The following definite checks should be made:

Before Each Flight.

1. Check fuel and oil levels.
2. Test ignition by running on each magneto alone.
3. See that oil and fuel pressure show on gages.
4. See that motor will turn up its usual revolutions per minute.
5. Drain water out of bottom of fuel tank.

Every Ten Hours, in Addition to the Above.

1. Check valve clearances with feeler gage provided in the Service Tool Kit.
2. Check valve springs by compressing by hand.
3. Check half balls in rockers (must not be stuck or pushed out).
4. Brush valve springs with oil.
5. Lubricate Zerk fittings with heavy oil.
6. Grease push rod ball tips with "No-ox-id E" or "Gredag."
7. Clean fuel strainer (ship).
8. Inspect fuel connections and fuel pump stuffing box, drain for leaks.

Every Twenty Hours, in Addition to the Above.

1. Change oil.
2. Clean oil strainer.
3. Inspect engine for oil leaks.
4. Clean spark plugs, look for broken insulation and adjust points if necessary.
5. Clean magneto points with cloth. N.B. (1) Do not use emery cloth. (2) Do not adjust breaker point clearance.

6. Oil magnetos as described in Scintilla Magneto instructions.
7. Check rocker arm end play and see that oil passages are not clogged up.
8. See that propeller hub is tight.
9. Check flow through fuel lines.
10. If benzol is being used in fuel, it is desirable to disassemble the carburetor every 50 hours to make sure that nothing is gummed up and that jets are clear.
11. Clean carburetor strainer.

Caution: In oiling the valve adjusting screws, do not push the valve off its seat with the oil gun pressure, as the push rod ball end may come out of its socket. Do not use too much oil, as it will force the ball out of its socket. After oiling, be sure that the ball turns freely in its socket.

To grease push rod ball tips which rest in the tappets, remove the push rod covers and push rods and dip the balls in grease such as "No-ox-id E" or "Gredag" and reassemble in exactly the same positions as before. Do not use anything but a high-grade acid-free non-fluid oil for the above operation. Ordinary yellow grease contains soap or other fillers, and is not suitable.

It is important to have the correct valve clearance on account of the danger of valve breakage which may result from running with excessive clearance. The proper valve clearance when cold is 0.010 in. for both the inlet and exhaust. This is measured between the valve stem and the half ball which pushes the valve open. It is necessary to lift up the rocker arm against the pressure of a light spring before the clearance gage can be inserted. In checking valve clearances the engine should be turned well past the point where the valve closes; otherwise a false indication of clearance will be had. A box wrench for the valve adjustment lock nut and a valve clearance gage are found in the tool kit furnished with each engine, as well as a tool for turning the adjusting screw. Do not try to check the valve timing with the running clearance of 0.010 in. A special adjustment of the valve clearance must be made before the engine can be timed. See "Timing the Valves of the Hornet" under Valve Timing. While the covers are off for the purpose of checking clearance it is well to look at the valve springs to make sure none are broken. A valve spring can be replaced without removing its rocker arm. Depressing the valve with the tool provided allows one to take off the push rod enclosure and push rod. The rocker arm can then be tipped up out of the way so there is room to take out the valve spring.

TOP OVERHAUL

Need for Top Overhaul.—The usual indication that an engine needs adjustment or possibly a top overhaul is the reduction in engine speed on the ground with full throttle. It should be borne in mind, in this connection, that extremes in temperature or barometer due either to atmospheric condition or altitude will affect the propeller speed sometimes as much as 50 to 100 r.p.m., and must be allowed for.

First check the mixture control to make sure that the lever on the carburetor is in the full rich position when the control lever in the cockpit is in the corresponding location. Next, check the spark advance at the magnetos in the same manner. At the same time check the magneto breakers with the feeler gage furnished for this purpose. The gap should be 0.012 in. The points should be smooth and free from oil. Clean the strainers in the fuel supply line, and be sure that fuel reaches the carburetor in adequate quantities. The best way to determine this is to disconnect the pipe at the carburetor, and open the fuel valves, observing whether the pipe runs full of fuel or not. The valve and magneto timing should be checked in accordance with instructions for timing the Hornet in the Valve Timing and Ignition Timing sections of this book.

After the foregoing checking has been done, and adjustments made, if necessary, start the engine and warm it up at low speed (800 to 1000 r.p.m.), until the temperature of the entering oil is at least 100° F. or 40° C. Next, try the engine at full throttle with the mixture control set full rich, and the spark full advanced. Observe the revolutions per minute, oil pressure, which should be between 75 and 100, and fuel pressure, which should be between 3 and 4 lb. Next, check the operation of the ignition by running first on one magneto and then on the other. If the ignition is found satisfactory and fuel pressure is 3 or 4 lb., and the engine still does not turn up to the required ground speed, it is probable that a top overhaul is necessary. One other check, however, is suggested; after the engine has been stopped by running the fuel out, and allowed to cool down for five minutes, the compression should be tried in the various cylinders. It will be necessary to turn the engine over two complete revolutions in order to test the compression in all nine cylinders. If this is found to be good, it is not likely that a top overhaul is needed and there is probably some other reason for the loss in revolutions.

Disassembly.—Tools for making ordinary adjustments and minor repairs are found in the canvas tool roll furnished with each engine. The following special tools are included in the set: Valve Spring Com-

pressor, Spanner for Inlet Pipe Nut, Cylinder Nut Wrench, Box Wrench for Valve Adjustment Lock Nut, Valve Clearance Gage.

First place the airplane in a clean, protected spot. Dust and dirt wear out more engines than anything else. Then remove the cowling surrounding the engine. Next, the engine should be thoroughly washed off with gasoline before attempting any disassembly work. With the engine thus prepared and some tins or boxes provided for the parts to be

FIG 88 Removing Push Rods from the Hornet Engine.

removed, the cylinder hats should be taken off. The push rod enclosures are removed by telescoping the tubes and locking them by means of a slight twist, after which the valve springs should be compressed by means of the tool provided in the tool kit. This will permit the removal of the push rods and enclosures. In this operation care should be taken that the valves are closed before trying to compress the springs. Although the push rods are marked at the tappet end to correspond with the cylinder numbers, it is best to lay them out in the order in

which they are removed from the engine. It is highly desirable that they be replaced in the exact position from which they came, as the ball ends have been worn to a perfect seat.

With the push rods removed, the next operation is to take off the inlet pipes. In doing this the spanner wrench provided should be used for loosening the packing at the bottom of each pipe before removing it. The packing nut should not be entirely unscrewed. Care should be taken in handling these intake pipes, as they are readily dented. Take off the oil sump, which is between the two bottom cylinders. There are two oil pipes which connect to the top of this casting. The rear one stays in the engine and the front one comes off with the sump. It is necessary carefully to pull the sump straight down in order to keep from bending these two pipes.

When assembling, do not force the sump up if something prevents the pipes from going together.

No. 1 cylinder should be removed last and installed first. This cylinder positions the master rod. A special wrench will be found in the tool kit to remove the cylinder stud nuts, after which the cylinder can be readily removed. In doing this, however, care should be taken not to allow the piston to drop and thereby become nicked. Care should also be taken not to mar the bottoms of the cylinder barrels. These should be carefully set down on wood in order not to distort or burr the end of the barrel.

Each piston must be brought up to the top of its stroke before its cylinder is removed. If this is not done, the scraper ring is likely to be broken in attempting to get it out of the crankcase.

As soon as any one cylinder has been taken off, the piston should be removed by pushing out the wrist pin. If this cannot be readily done, the head or top of the piston should be slightly heated by means of a blow torch, and the pin tapped out by using a fiber drift shaped to fit the wrist pin plug. Care must be taken not to drive these pins with any considerable force. The application of more heat will expand the piston sufficiently to enable the pins to be removed with ease.

Inspection of Connecting Rods.—With the cylinders removed, an inspection should be made of the master connecting rod and link rods. By moving each one, both up and down and sideways on the crankpin, a rough check can be made of the clearances. If these parts are in good condition, very little play will be found in the master rod, except sideways on the pin. The link rods, however, will feel somewhat loose, as they have normally 0.002-in. clearance on the diameter of the pin, and 0.006 to 0.008 in. sideways. It is advisable to try the wrist pins in their respective rods. It should not be possible to insert more than a 0.002-in.

feeler between the pin and the bushing. If more than 0.003-in. clearance is found, it is desirable to replace the bushing.

The link rod bushings should be examined for excessive wear or roughness. The maximum clearance to be allowed is 0.003 in. on the piston pin bushing and 0.0025 in. between the knuckle pin and its bushing. The side clearance between the master rod and the link rod should not exceed 0.010 in. If excessive wear is shown or if the bushings are scored or scratched, they should be replaced. The surface of the knuckle pins should be smooth. Any slight roughness can be stoned down, but deep scratches indicate that the pin should be replaced. Make sure that the oil plugs inside the knuckle pins are tight and without any evidence of leaking. The maximum clearance to be allowed between the master rod bearing and the crankpin is 0.006 in., and the end clearance of the master rod should not be more than 0.020 in. Blow out the oil passages in the master rod.

Pistons.—The pistons should be carefully cleaned and examined. The wrist pin should be a push fit at room temperature, or 70° F. If it is too tight, the piston should be carefully reamed to provide the proper fit with the reamer in the station tool equipment. In this connection, it should be noted that in cold weather, because of the contraction of the aluminum, the pin will be tighter than normal. Examine the wrist pin bosses for cracks.

The piston rings should bear around their entire circumference, and preferably have no more than 0.025-in. end clearance while in the cylinder. Moreover, they should be entirely free in the ring grooves. A convenient method of checking the end clearance of a ring is to put a piston in the cylinder and then put the ring in place against the end of the piston. This will make it easy to insert a feeler in the ring gap and determine the exact clearance. If it is necessary to replace rings which do not meet these requirements, it is desirable to put the new rings in the lower grooves. In this way, the old rings which fit the cylinders will provide proper protection for the new rings until they are run in. New oil rings should be used if the scraping surface is more than half the width of the ring. Be careful not to spread the rings any more than necessary in removing or replacing them. Rings with less than ¼-in. gap when free should be replaced because their tension is too low. Five pounds is the minimum tension that may be satisfactorily used. The ring tension is tested by resting one side of the ring on a platform scale with the slot at one side (90° from the point of contact with the scale) and noting the amount of pressure that must be applied to the top of the ring to close the slot.

The question of replacing rings generally depends on the performance

of the engine. If oil consumption is excessive, it is well to install new rings. If the side clearance of the rings is as much as 0.012 in., it is well to install new ones regardless of the oil consumption.

If it should be necessary to replace a piston, the new piston must not be more than 0.03 lb. ($\frac{1}{2}$ oz.) different in weight from the one it replaces. The weight of the piston will be found on the under side of the skirt. The lower end of the piston may be bored out for balancing, but not larger than $5\frac{1}{8}$-in. diameter.

In replacing the No. 1 piston of Series A Hornets, the Series A–1 piston must be used. For replacing the other piston the new piston may be used. When the new piston is used in Series A engine, brass piston pin plugs must be used instead of the standard used with regular equipment. The master piston of the A–1 differs from the other pistons in not having an oil relief under the lowest compression ring groove. The master piston has three compression rings and an oil scraper ring. The other pistons have two compression rings and two oil scraper rings.

When new rings are fitted, the end clearance should be between 0.008 and 0.015 in. The side clearance for the various rings, beginning at the top, should be as follows: 0.004 in., 0.0035 in., 0.003 in., 0.0025 in., 0.0015 in.

Rings can be obtained from any Pratt & Whitney Service Station which are 0.020 in. wider than standard. In cases where the grooves are slightly worn on the sides, but are uniform and do not contain ridges or steps, overwidth rings may be ground down on a surface grinder so as to obtain the above clearances. If the grooves are in bad condition, they will need to be recut before new rings are fitted. If the side wear is more than 0.020 in. the piston should be scrapped, because of the reduction in width of the lands between the rings.

Cylinders.—Cylinder barrels should be examined for taper and roundness by the use of an inside micrometer. Cylinders tapered or out of round more than 0.003 in. should be replaced. The inner surface, of course, should be smooth. The cylinder barrel and cylinder head are permanently attached to each other and cannot be detached. In case a cylinder is damaged by over priming, running without oil, or in other ways, it is necessary to replace the complete cylinder.

Replacing Valve Guides.—The inlet and exhaust valves are of different diameter, and it will be found that the station tool equipment includes two sets of tools for handling the valve guides. The valve guides should be drilled out. To do this, remove the valve and valve spring. Insert drill from the valve spring end of guide. This drill is provided in the station tool kit. Drill to within approximately $\frac{1}{4}$ in. of bottom of guide in cylinder. Insert drift provided in station tool

kit and drive remainder of guide out towards the valve seat. (When the drill passes the undercut in the valve guide the head of the guide may be removed from the valve spring end.) After removing the guide examine the new guide for burrs. Drifts are furnished in the station tool kit for driving the guide in. Smear the guides with a light coating of oil and graphite. Heat the cylinder head to about 200° F. before trying to put in the new guide. Heating can be accomplished by directing a gentle blowtorch flame on the aluminum guide boss inside the part. Drive in the guide. Reamers and plug gages are supplied, and each new guide must be carefully reamed to fit the proper gage.

In case the hole in the cylinder head is damaged in removing a guide, an oversize guide may be used. These are furnished 0.010 in. larger in diameter than the original guides. The hole in the cylinder head must be carefully reamed so as to be 0.002 in. smaller than the new guide, to give the required tight fit.

Removing Valves.—To facilitate the handling of the valves, a block of wood should be secured between 5 and $5\frac{1}{2}$ in. in diameter and 11 in. long, and rounded at the upper end to fit the cylinder dome. Care should be taken that this wood is kept clean, as chips or dirt will readily mar the cylinder barrels. By placing the cylinder over this block, the valves will be held shut and it will be easy to remove the valve springs by using the tool provided. It is not necessary or desirable to remove the rocker arms to take out the valve springs. As soon as the spring has been depressed, the split cone can be removed and the valve washer and valve springs taken out. After this is done, the locking wire should be removed; this will be found snapped into a groove near the outer end of the stem. Next, be sure that there is no burr on the valve stem, particularly at the edge of the lock wire groove. In case there is, it should be removed with a fine file before attempting to remove the valves.

An examination should be made of the valve stems and their clearance in the valve guides before any regrinding is attempted. Care should be taken not to use emery cloth on the valve stems unless absolutely necessary, since it removes the glaze resulting from continued operation of the engine.

The rocker arms should move freely. If their bearings seem to be tight, they may have hard carbon on the ball tracks and should be washed out. The rocker bearings must not be too loose. If the end of the rocker can be wiggled sidewise, the bearings should be adjusted. Bearings which feel bumpy when turned after being washed out probably need replacement.

The guide clearance can be checked by means of plug gages furnished in the station tool equipment. The maximum permissible clearance for

the inlet valve stem is 0.008 in. and for the exhaust valve stem 0.012 in., and it is generally best to make replacements before this amount of wear has occurred.

Valve Grinding.—Before attempting to regrind the valves, any excessive carbon should be removed from the cylinder heads, great care being taken not to mar the valve seats during the operation. The

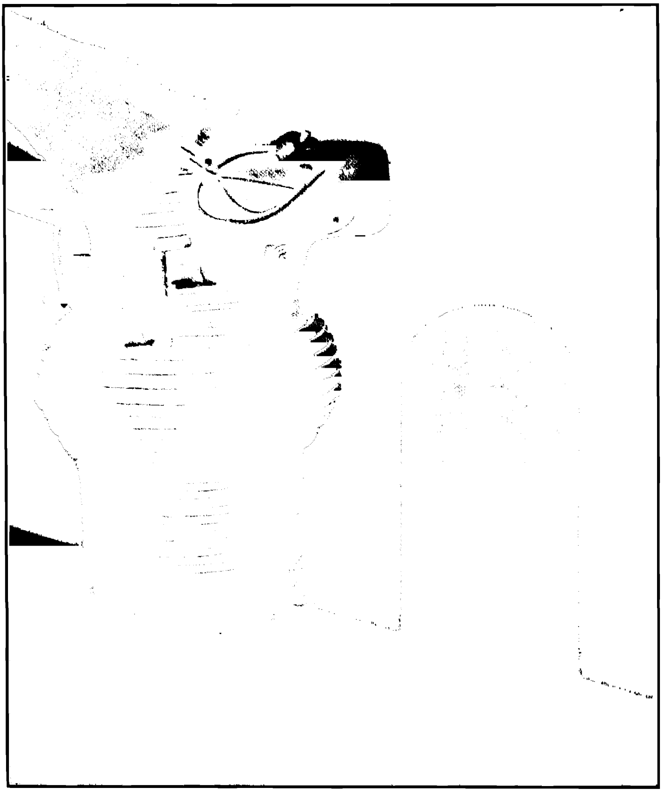


FIG. 89.—Removing Valve Spring. Use Wooden Block Inside Cylinder to Hold Valve Closed

carbon should also be removed from the cylinder side of the valves. The valves should be carefully handled in order to avoid scratching or burring the seat.

Valve grinding tools are provided for holding the inlet and exhaust valves while grinding. The grinding compound should be kept away from valve guides and cylinder bores, and all traces of it should be washed away after the grinding operation is finished.

As a rule, it should not be necessary to re-cut the valves or seats, lapping with grinding compound being sufficient to put both the valves and seats in good condition. After the valve grinding has been completed, the parts should be very thoroughly cleaned before reassembling and the valve stems oiled, as well as the rocker balls, push rod balls and rocker arm bearings.

Be Sure to Replace the Safety Snap Rings on all Valve Stems as Soon as the Valves Have Been Put into Their Guides.—In replacing any valve springs which may be broken or rusted, use the same type as those removed.

On engines on which the lift of the inlet valve is $\frac{1}{8}$ in. greater than that of the exhaust, use

1823 Outer Valve Spring (8 turns)
1824 Inner Valve Spring (9 turns)

The number of turns specified above is the total number of coils in the spring.

If the engine has run 500 hours or more, all valve springs should be tested for tension. The springs should not show less than the following load when compressed to the length shown:

	Inner		Outer		Length when Tested, Inches
	Part Number	Load, Pounds	Part Number	Load, Pounds	
Hornet Series A . . .	1824	52	1823	69	$1\frac{11}{16}$
Hornet Series A-1	1824	52	1823	69	$1\frac{11}{16}$

All springs which have less tension should be replaced. Rusty springs should also be replaced, as they are likely to break. Valve springs should be brushed with oil as described under Periodic Inspection.

Rocker Arms.—In order to replace the ball cup in rocker arms, it is best to drill a $\frac{1}{8}$-in. hole through the top of the rocker socket. Do not drill into the steel cup. Drive the cup out, using a punch. Countersink the hole on the inside of the rocker to be sure there is no burr. Plug hole with a piece of brass. Do not allow the brass to project into the rocker. Put in new ball cup.

Before putting new bearings in a rocker arm, measure the thickness of the internal flange in the rocker and also of the spacer which goes

between the two bearings. The spacer should be the same thickness as the flange or can be as much as 0.002 in. thicker, but must not be thinner. **Replacement must always be made with the special bearings supplied, as ordinary ball bearings of the same type have insufficient load capacity.** Each bearing should be a light press fit in the rocker and a snug hand fit on the shaft. Be sure to insert the spacer between the two bearings. When installed in the cylinder head with the shaft nut pulled up tight, the rocker should move freely without any sign of binding, and have no side play.

In the case of bearings which have developed side play but which are otherwise all right, the spacer may be made thinner in a surface grinder. The faces of the spacer must be kept parallel within 0.0005 in., and it will be found that very little material will have to be removed in order to take out considerable side play of the rocker.

Assembling.—To reassemble the engine, replace the No. 1 piston on the master rod with the piston number facing the propeller. Carefully space the piston rings so that the slots on the compression rings are 120 degrees apart; in other words, so they are spaced equally around the piston. *See that the oil scraper ring is in place, with the scraping edge toward the bottom.* Next, carefully oil the piston with clean engine oil, and wipe out the cylinder barrel and oil it. After this is done, compress the piston rings by means of the ring clamp provided in the station kit, and put on No. 1 cylinder, which should be carefully and completely fastened down before attempting to install the next cylinder. The hold-down nuts should be tightened down evenly all around with the wrench provided and safety wired. Repeat the above process for the installation of the other eight cylinders, and then replace the push rods in their enclosing tubes, being careful to put them back in the same position as they formerly had. Moreover, be sure that the gaskets at both ends of the enclosure tubes are in good shape and in proper position. Next, attach the intake pipes, being careful that the packing end of the pipe is round and smooth. The three-cornered intake gasket on the cylinder should be in good condition. If not, replace it. Do not tighten down on the packing nuts with anything but the spanner wrench provided in the tool kit, and note that these nuts should not be tightened up too tight, or damage will be done to the intake pipes.

With the cylinders, push rods, and intake pipes in place, set the valve clearance to 0.010 in., using the box wrench provided. It is essential to turn the engine half a revolution from the intake closing before attempting to set the tappet clearance for any particular cylinder. This will insure that the valves are on their seats. As there is a spring in each tappet which keeps the push rod engaged with the rocker arm, it

is necessary to lift the rocker arm in order to insert the clearance gage It is not necessary to re-time the engine after a top overhaul, as the cam mechanism is not disturbed.

Before replacing the oil sump, remove the screen and clean it. Be careful that the front pipe is in place in the sump and the rear pipe in the blower section, and that both are round and smooth. *Do not force the sump up into place.* The suction pipe which takes oil from the bottom of the sump must have a good gasket and must be bolted up tight.

Before attempting to start the engine, the routine inspection referred to in the division on Periodic Inspection should be conducted.

Running In.—It is desirable to operate an engine which has been given a top overhaul for two to three hours, starting slowly and gradually increasing speed, before attempting to run the engine at full throttle or fly the plane. This running should be done before replacing the engine cowling. Afterwards a check should be made for oil leaks and the tightness of all connections, etc. If a whole new set of rings has been used on any one piston, or other new parts installed, it is desirable to run the engine at least two hours more, and it is preferable to operate it with the least possible amount of full-throttle running for five or ten hours thereafter, in order that the new parts may be properly run in and seasoned. If the engine turns up to its customary ground speed, and the oil pressure is between 75 and 100 lb. at full throttle, the engine can be considered in good shape and ready for further service. After running in, the valve clearance should be re-checked, as the valves may have bedded in somewhat. The engine must be cold when the clearance is checked, or a false indication will be given.

CONDENSED LIST OF CLEARANCES

From Table of Fits of Pratt & Whitney Handbook

When three figures are given the second figure indicates the *desired* fit. The other two give the tightest and loosest fits permissible. Dimensions given in inches.

	Minimum	Desired	Maximum
Valve Tappet and Pin	0.0005 L.	0.001 L.	0.002 L.
Valve Tappet Roller and Pin	0.0005 L.	0.001 L.	0.0025 L.
Valve Tappet and Valve Tappet Roller Side Clearance	0.008 L.	0.014 L.	0.020 L.
Valve Tappet Guide and Roller Side Clearance	0.003 L.	0.003 L.	0.006 L.
Tappet Guide and Pin	0.002 L.	0.005 L.	0.014 L.

FROM TABLE OF FITS OF PRATT & WHITNEY HANDBOOK—*Continued*

	Minimum	Desired	Maximum
Tappet Guide and Roller Pin End Clearance	0.021 L.	0.031 L.	0.041 L.
Cylinder Head and Valve Seat	0.0065 T.	0.008 T.	0.0095 T.
Exhaust Valve and Valve Guide	0.0065 L.	0.007 L.	0.013 L.
Cylinder Head and Valve Guide Inlet and Exhaust	0.0005 T.	0.002 T.	0.0025 T.
Inlet Valve and Lock—End Clearance	0.001 L.	0.004 L.	0.007 L.
Inlet Valve and Valve Guide	0.0015 L.	0.002 L.	0.008 L.
Master Rod and Bushing	0.0015 T.	0.002 T.	0.0045 T.
Piston Pin and Bushing	0.00175 L.	0.0025 L.	0.00325 L.
Master Rod and Bearing	0.001 T.	0.001 T.	0.002 T.
Articulated Rod Pin and Master Rod	0.0005 L.	0.000	0.001 T.
Articulated Rod Pin and Plug	0.001 T.	0.0015 T.	0.003 T.
Master Rod and Bushing—End Clearance. Fit at Assembly to	....	0.006 L.	0.008 L.
Articulated Rod and Master Rod End Clearance	0.011 L.	0.015 L.	0.019 L.
Articulated Rod Pin and Bushing	0.001 L.	0.0015 L.	0.0025 L.
Articulated Rod and Bushing	0.0015 T.	0.002 T.	0.0045 T.
Oil Pressure Relief Body and Plunger	0.002 L.	0.003 L.	0.006 L.
Front Main Bearing and Crankshaft	0.0003 L.	0.000	0.0014 T.
Front Main Bearing and Liner	0.0005 T.	0.001 L.	0.0017 L.
Front Main Bearing Liner and Case Large Diameter	0.011 L.	0.031 L.	0.051 L.
Crankpin and Bearing—End Clearance	0.000	0.012 L.	0.020 L.
Crankpin and Bearing—Diameter	0.004 L.	0.004 L.	0.007 L.
Piston Pin and Plug	0.0025 T.	0.003 T.	0.0045 T.
Piston and Piston Pin	0.00015 L.	0.0003 L.	0.002 L.
Piston Skirt and Cylinder Sleeve	0.022 L.	0.024 L.	0.026 L.
Piston and Cylinder Sleeve between Rings	0.026 L.	0.028 L.	0.030 L.
Valve Adjusting Screw and Oiler	0.001 T.	0.003 T.	0.006 T.
Valve Rocker and Cup	0.0005 T.	0.001 T.	0.0025 T.
Cylinder Head and Push Rod Tube Main	0.004 L.	0.015 L.	0.036 L.
Cylinder Head and Valve Rocker Bushing (Inside)	0.001 T.	0.002 T.	0.003 T.
Valve Rocker Shaft and Bushing (Inside)	0.001 L.	0.0002 L.	0.0005 T.
Valve Rocker Shaft and Bearing	0.0000	0.0004 L.	0.0008 L.
Valve Rocker and Bearing	0.0007 L.	0.0000	0.0008 T.

FROM TABLE OF FITS OF PRATT & WHITNEY HANDBOOK—*Continued*

	Minimum	Desired	Maximum
Cylinder Head and Bushing (Outside)...	0.001 T.	0.002 T.	0.003 T.
Valve Rocker Shaft and Bushing (Outside)	0.0001 L.	0.0005 L.	0.001 L.
Valve Rocker Shaft and Cylinder Head End Clearance	0.004 L.	0.020 L.	0.047 L.
Crankshaft and Propeller Hub Spline, O. D	0.003 L.	0.006 L.	0.012 L.
Crankshaft and Propeller Hub Spline, I. D	0.001 L.	0.006 L.	0.013 L.
Crankshaft and Propeller Hub Spline Side Clearance	0.0002 L.	0.001 L.	0.0038 L.
Valve Guide and Washer	0 002 L.	0.013 L.	0.0026 L.
Piston and Ring Side Clearance Top Grove	0.0000	0.003 L.	0.0000
Piston and Ring Side Clearance Second Groove	0.0000	0.0025 L.	0.0000
Piston and Ring Side Clearance Third and Fourth Grooves	0.0000	0.002 L.	0.0000
Piston and Ring Side Clearance Bottom Grooves	0 0000	0.0015 L.	0.0000

CHAPTER XII

THE KINNER K-5 ENGINE *

Just as the Hornet Engine has served as an example of modern, high-powered engine design, the following description of the Kinner K-5 Engine is given as an example of the low-powered class.

The Model K-5 Engine is a popular 100 h.p., five-cylinder engine of the fixed radial type. The engine carries a U. S. Department of Commerce Approved Type Certificate No. 3, and is rated 90 h.p. At 1825 r.p.m. the engine develops 100 h.p. at sea-level.

The proven efficiency and dependability of the Kinner Engine, coupled with its modest cost, has resulted in its installation in a large number of airplanes requiring 100 h.p.

The accessories and push rods are at the rear of the engine, and the front crankcase being stream-lined, the engine creates as little drag as is possible with a radial engine.

SPECIFICATIONS

Model.—K-5.
Rated H.P.—90.
Actual Brake H.P. at Sea-level.—105 h.p. at 1900 r.p.m.
Type of Engine.—Air-cooled static radial.
Number of Cylinders.—Five.
Length of Engine Less Starter.—32¼ in.
Overall Diameter.—44⅜ in.
Bore.—4¼ in.
Stroke.—5¼ in.
Displacement of Engine.—372 cu. in.
Compression Ratio.—5.0 to 1.
Type of Piston.—Heat-treated aluminum alloy.
Number of Piston Rings.—Four per piston.
Ignition System.—Two Scintilla single-spark high-tension magnetos.
Carburetor.—Stromberg or Holley. One 2-in. single-barrel accelerating well type.
Type of Crankshaft.—Single-throw, one-piece, counterbalanced.
Type of Oil Pump.—Gear.
Desired Oil Temperature.—120° to 140° F.
Desired Oil Pressure.—90 to 100 lb.

* The data in this section were arranged through the cooperation of Kinner Aeroplane & Motor Corporation.

Maximum Oil Consumption per B.H.P. Hour.—.020 lb.
Average Fuel Consumption (cruising speed).—36 lb. or 6 gal. per hour.
Average Fuel Consumption (full throttle, 1900 r p.m) —66 lb or 11 gal. per hour.
Speed of Propeller.—Crankshaft.

FIG 90.—Three-quarter Rear View of the Kinner K-5.

Speed and Direction of Rotation of Tachometer Shaft.—½ anti-crankshaft
Firing Order.—1, 3, 5, 2, 4
Valve Timing Clearance (cold) —0 020 in Hot clearance approximately 0 025 in. greater

Valve Timing (cold clearance).—Inlet opens 29° early, inlet closes 81° late; exhaust opens 75° early, exhaust closes 35° late.

Ignition Timing.—Left magneto 26° before firing top center fully advanced. Right magneto 25° before firing top center fully advanced.

Weight of Engine (dry without hub, air heater or exhaust stacks).—275 lb. plus or minus 5 lb.

Hub, Heater and Stacks.—18 lb.

CONSTRUCTION

Crankcase.—The crankcase is cast from heat-treated aluminum alloy and comprises three sections: the main cylinder section, the internal-ribbed section, and the rear cover. Inspection of the crankshaft, bearings, connecting rods, cam followers, tappets, guides, cam gears, and magneto drive gears is made possible by the removal of the front and rear crankcase covers. See Fig. 91.

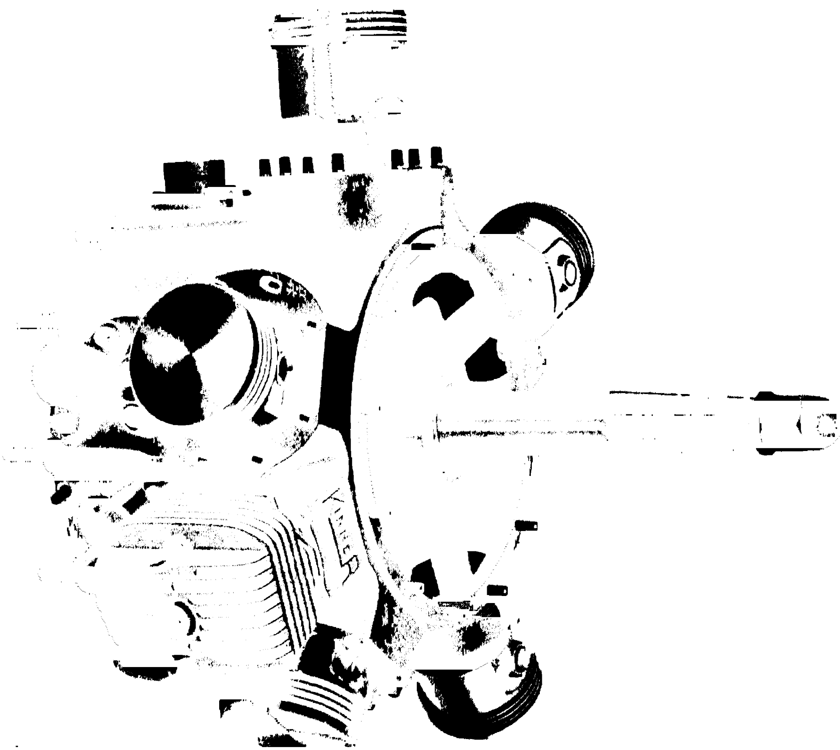


FIG. 91.—Crankcase Assembly of the Kinner K-5.

Crankshaft.—The crankshaft is a one-piece, single-throw, counter-balanced, heat-treated, steel, drop-forging, machined all over. The shaft is drilled for lightness and for the passage of oil under pressure. The propeller end of the shaft is No. 1 S.A.E. taper standard. The crankshaft is supported by two main bearings, which are plain bearings, while a radial ball bearing takes the propeller thrust, but carries no radial load. See Fig. 92.

Connecting Rods.—The split-type master rod and four link rods are heat-treated, steel, drop-forging, of H-section. The master rod bearing is a plain, babbitt, bronzed-backed bearing, and the link rods have special bronze plain bearings. The piston pins are full floating

FIG. 92.—The One-piece Crankshaft of the Kinner K-5.

and provided with aluminum buttons to prevent the piston pins from scoring the cylinder walls. See Fig. 93.

Pistons.—The pistons are of conventional design, of heat-treated, aluminum alloy, cast with internal ribs for strengthening and to facilitate cooling. Each piston is fitted with three compression rings and one oil control ring. See Fig. 93.

Cylinder Assembly.—The cylinder barrel and cooling fins are machined from a single carbon-steel forging. The cylinder head is heat-treated, cast aluminum alloy, and is held to the cylinder barrel by studs and nuts. Bronze-alloy valve guides are pressed into the head. Hard aluminum bronze valve seats are shrunk in the head.

Valve Mechanism.—Each cylinder head is fitted with two non-interchangeable, wear-resisting, chromium-alloy steel valves. The

valves are hollow and tulip shaped. The valves are opened by rocker arms operated by push rods and tappets riding upon individual cams. Double helical springs close the valves. Five camshafts, driven by the timing pinion at the rear end of the crankshaft, operate the cam followers and push rods which open the valves. The push rods are ball-ended to fit into the rocker arm socket and cam follower socket. By means of the screw socket, the clearance at the valves is adjustable.

Carburetion.—A single-barreled Stromberg Carburetor, type NAR–5A, supplies carburetion, or a Holley Aviation Carburetor may be fur-

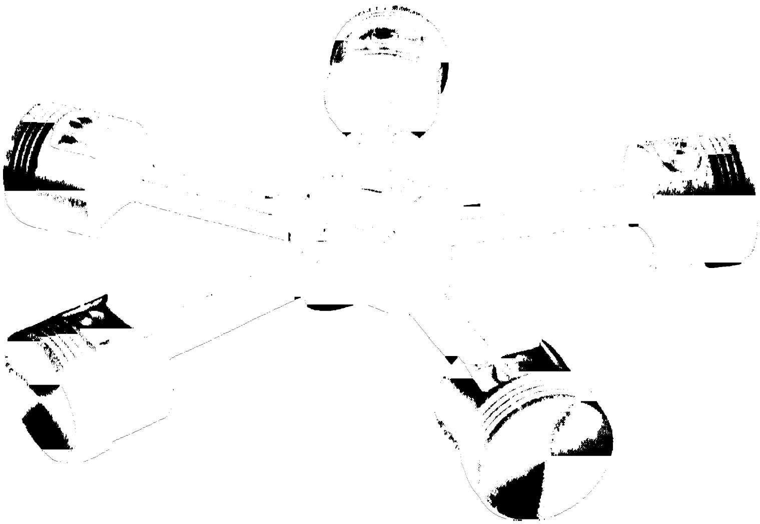


FIG. 93.—The Connecting Rod Assembly of the Kinner K-5.

nished. Both types of carburetors are equipped with a manually operated altitude control. Heat application to the induction system is furnished by a special air heater which draws heat from No. 3 cylinder. The heat is controlled by a cut-off valve in the exhaust line, so that the heat application may be regulated to meet weather conditions.

Ignition.—Ignition is furnished by two Scintilla magnetos, type PN–5D, equipped with manual control for advancing and retarding the spark. The right magneto fires the front plugs, and the left magneto fires the rear plugs.

Lubrication System.—The lubrication system is the conventional dry sump, pressure arrangement, common to most aircraft engines. A

gear pump forces oil through the crankshaft from the main bearing to the rear and out by an oil pressure relief valve on the rear cover. The two main bearings and the master rod bearing are supplied with oil under pressure, and all other internal parts are lubricated by means of the spray resulting from the bearings bleeding. A scavenger pump draws the collected oil from the sump and returns the oil to the tank. See Fig. 85.

OPERATION

Preparation of the Engine before Starting.—The routine to be followed in preparing the engine for service depends to some degree upon whether the engine has been in daily service or in storage. Preparing a new engine for service likewise calls for special treatment.

If the engine is new or has been out of service for a long time, the spark plugs should be removed and a small quantity of oil (about a tablespoon) injected into each cylinder in order to lubricate positively the pistons and cylinder walls. The propeller should then be turned about a dozen complete revolutions, so that the oil will be distributed over the piston and the cylinder walls. The engine should then receive the customary inspections recommended daily, as well as the five-hour and fifteen-hour inspections, including filling the fuel tank with domestic aviation gasoline, cleaning the gasoline strainer, draining any possible accumulation of water from the carburetor and fuel tank, making certain that no air is trapped in the strainer or fuel supply line, draining the oil from the engine and oil tank, and flushing with light lubricating oil if the engine was not drained before removing from service. The oil supply tank should be filled with a recommended grade of oil, allowing room for expansion of the oil when it is heated.

The propeller nut should be checked for tightness, using a thirty-inch bar; the propeller should be checked for track, and caution should be exercised in seeing that the propeller nut is cottered.

All nuts and bolts on both the engine and mounting should be examined to see that they are tight and properly locked.

The rocker arms must be lubricated with a pressure gun, using a grease recommended for rocker arms. Do not use 600 W or common grease.

The magnetos should be oiled, and the ground wires checked to see that they are connected to the magnetos.

All controls must be checked for open and closed positions and to be certain that they are clear.

The fuel supply tank, fuel supply line, carburetor, and all oil lines must be examined thoroughly for leaks.

The tachometer connection, oil pressure gage, and oil temperature connection should be inspected to see that they are correctly connected.

The priming pump, priming lines, and valves should be checked to determine whether they are in proper working order.

Starting the Engine.—The starting of the engine is governed by climatic conditions. In cold weather it is necessary to heat the oil before making any attempt to start the engine, and as cold weather makes a decidedly rich mixture compulsory, caution must be observed in using the primer, or the piston and cylinder walls will be damaged through washing away the lubricating oil.

The ignition switch should be placed in the "off" position, and the engine primed. The mixture control should be set at full rich, and the idle adjustment at full rich in cold weather and half lean in hot weather. The throttle should be slightly cracked, and the spark fully advanced if starting is to be done by swinging the propeller by hand. If a mechanical or air-starter is used, the spark should be retarded one-half inch. With an impulse coupling, the propeller must not be turned too fast, for the coupling will not function over 50 r.p.m. Functioning of this coupling is facilitated by flooding the coupling with kerosene.

Observations at Start.—After the engine has been started, the oil pressure gage should be noted, and if pressure is not registered on the gage after twenty to thirty seconds, the engine should be immediately stopped, and the cause of the no pressure condition must be determined. **Under no conditions should the engine be operated more than a half minute without oil pressure showing on the gage.**

The engine should be run between 850 and 900 r.p.m. by slowly opening the throttle. With cool oil the oil pressure may show an excess of 100 lb., but the pressure will drop to normal as the oil temperature increases.

No attempt should be made to hurry the warming-up process. The engine is equipped with aluminum alloy pistons, which are properly fitted for operation under normal temperature conditions, while the cylinder barrels are steel. The pistons and cylinders are exposed to the same source of heat, but the pistons with their greater conductivity and expansion enlarge more rapidly than the cylinders. From this fact, it is obvious that rapid acceleration of a cold engine may result in the pistons sticking in the barrels and causing damage to the pistons and barrels as well as to other vital parts of the engine.

Once the engine is thoroughly warm and the oil has reached the desired temperature of 120° F., the engine should be tested for a moment or two at full throttle, noting the oil pressure and the tachometer reading. The engine speed on each magneto should be tested to deter-

mine whether both magnetos and both sets of spark plugs are functioning correctly. The throttle, however, should not be held in the wide-open position more than a few moments, because of the fact that the slip-stream from the propeller does not cool the engine very well, and overheating may result. Prolonged running on the ground or idling of the engine below 600 to 700 r.p.m. will result in serious injury to the engine.

The Engine During Flight.—The oil pressure and oil temperature should be noted frequently while the engine is in the air, for by doing so the condition of the engine may be determined. The oil pressure should not show less than 90 lb. and while less pressure may not be an indication of trôuble, a drop below 50 lb. calls for an immediate landing.

Under normal conditions the oil temperature should not exceed 180° F., and unless such a temperature is due to climatic conditions, it is an indication of trouble. Any temperature in excess of 180° F. indicates serious trouble, and the airplane must be landed as soon as possible.

When the airplane is on the ground and has been taxied to position, the engine should be allowed to run for a few minutes at 600 to 700 r.p.m. This permits a slow cooling of the valves and prevents the valves from warping. The customary practice is to shut off the fuel supply and allow the engine to run until the fuel in the carburetor has been consumed. Be sure that the ignition switch is placed in the "off" position after the engine stops.

PERIODICAL INSPECTIONS

Daily or Every Five Hours of Flying.—A general surface inspection should be made after each flight, and the engine prepared for immediate flight. Any items suggested by the pilot should receive attention immediately. The magneto breaker contacts should be checked for gap and cleanliness. Gap: 0.012 in.

Check all bolts and nuts for tightness and locking. The cylinder head joint nuts are not expected to be in need of attention between overhauls. The cylinder head joint nuts should be checked only when the heads are cold. Be careful that the nuts are not drawn up tight enough to pull the studs from the aluminum alloy heads. The nuts should never be tightened when the engine is hot, since the strength of aluminum is much lower when hot than when cold.

The rocker arms should be lubricated with a Zerk gun, using a good quality of rocker arm lubricant. Put kerosene or light oil on the valve stems through the opening in rocker arm cover.

Check the oil in the oil tank, and see that the fuel tank has a sufficient amount of gasoline of aviation grade.

Clean the gasoline strainer and replace, making certain that no air is trapped in the strainer. Remove the strainer from the carburetor, clean, and replace.

Oil all spark, mixture, and throttle controls.

Servicing after Fifteen Hours of Flying.—Besides the inspections required under the five-hour period the following inspections should be made at the end of fifteen hours of flying:

Examine the propeller nut for tightness.

Check the intake pipe cap screws and clamps.

If the engine has been out of service for a long period of time, it should be run at part throttle fifteen or twenty minutes twice a week.

Remove rocker arm cover. Oil the push rod, ball ends with rocker arm lubricant or a graphite oil. Never put graphite on rocker arm axle.

Check the valve clearances according to specifications on the engine name plate. To adjust the valves, proceed as follows: Turn the propeller until the inlet valve of No. 1 cylinder is seen to open and close. When the inlet valve is observed closing, the piston for No. 1 cylinder is ascending upon the compression stroke, and the piston should be stopped when top center is reached. Adjust the valves of No. 1 cylinder, and then proceed to adjust the valves of the remaining cylinders according to the firing order 1, 3, 5, 2, 4. In turning the propeller after No. 1 has been adjusted, 144° movement will bring the piston of No. 3 cylinder to firing top center, and another propeller movement of 144° will bring the piston of No. 5 cylinder to firing top center, etc.

The adjustment to the valves is made by loosening the clamping bolt in the rocker arm and by turning the ball socket with a screw-driver. **Do not forget to tighten the bolt after adjustment.** Lubricate the rocker arm axle.

When adjusting the rocker arms, inspect the cotters in the valves, both the safety cotters in the valve stem and the cotters through the valve nut. If these are worn or damaged, replace with the special piano-wire pins furnished by the Kinner Company. Ordinary cotter pins are not suitable for this purpose.

TOP OVERHAUL

If a reduced r.p.m. at full throttle persists after allowance has been made for weather conditions, such as wind, extremes in humidity, tem-

perature or barometer, due to atmospheric conditions or altitude, it is an indication that the engine is in need of a top overhaul. Before starting a top overhaul, the engine should be checked as follows:

1. Check the mixture control and be absolutely certain that the lever on the carburetor is in the rich position.

2. Clean the gasoline strainers and fuel supply line, and be certain that fuel reaches the carburetor in adequate quantities.

3. Examine the magneto breaker contacts for correct gap of 0.012 in. and for cleanliness and alignment.

4. After the engine has been stopped by running the fuel out and allowed to cool for at least five minutes, the compression should be checked in all the cylinders. If the compression is found to be normal in all five cylinders, there is some other reason for loss of power and reduced r.p.m. If the compression is found to be the same in all cylinders but is questionable as to correctness, a top overhaul should be given the engine. The amount of labor involved to disassemble and inspect the engine is so small that it is not advisable to operate it if there is the slightest suspicion that it is in need of attention.

The top overhaul consists of the following:

The engine should be thoroughly cleaned on the outside with a spray gun and gasoline. The more thoroughly this job is done the more assurance there is that dirt will not find its way inside the engine when the cylinders are removed.

The exhaust and intake systems should be removed and inspected during dismantling. The spark plugs and wiring should be removed and examined, and any wiring which shows deterioration should be replaced.

The oil sump and oil screens should be carefully cleaned.

Remove the valve push rods and examine the valve mechanism for possible wear. Lay out each part, so that it can be replaced in its original position. This is very important, for the ball ends have become seated in their respective sockets and must not be replaced in strange sockets.

The engine crankshaft should be turned until No. 1 piston is at top center. Remove the cylinder, hold down nuts, and pull cylinder off, at the same time holding the push rods.

When the cylinder has been removed from No. 1, the piston should be taken off the connecting rod immediately so as to avoid injury. The piston may be removed by tapping out the wrist pin with a fiber plug.

Remove the remainder of the cylinders and make a rough check of the clearances at the master rod and the link rods by moving them up and down and sidewise. Unless the engine has seen sufficient service

to warrant a major overhaul, these parts will very likely be found in good condition.

If the engine internally is not particularly dirty, it is not advisable to wash the connecting rods, as it is impossible to re-oil the parts satisfactorily. While the cylinders are being overhauled, cloth or paper should be tied about the crankcase of the engine to protect the interior from dust and dirt.

Removing Valves.—A clamp stand for holding the cylinders will facilitate the operation of removing the valve springs. The rocker arms do not have to be removed in order to take out the valve springs. Before the valves are withdrawn, it should be noted whether there are any burrs on the stems, particularly at the edge of lock wire oil groove. Any burrs on the valve stems should be removed with a fine file, or they will injure the valve guides when the valves are withdrawn.

Before the valves are ground, all the valves should be checked for clearance in the guides. Any guide showing an excessive clearance must be replaced. The carbon should also be removed from the cylinder head before the valves are ground, care being taken not to scratch the valve seat during this operation.

During the process of grinding the valves the precaution must be taken that no grinding compound finds its way to the valve guides or upon the cylinder bore. It is very difficult to wash away the grinding compound, as it becomes lodged in the pores of the metal.

After the valves have been ground, they should be subjected to the gasoline test by pouring gasoline into the valve ports and observing whether there is a seepage into the cylinder heads.

If the valve seats in the cylinder require refacing, this should be done without separating the barrel from the head.

Inspection of Pistons and Rings.—The piston rings should be examined to determine whether they are bearing around their entire circumference, and have no more than 0.020-in. end clearance when the ring is in the cylinder. The rings should be free in the ring grooves and have a minimum of 6-lb tension. If any of the rings require replacing, the new rings should be placed in the lower grooves where they will be protected by the old rings from combustion heat until they have been run-in. The oil control rings should be replaced if the scraping surface is more than one-half the width of the ring. The oil control rings should be installed with the bevel side up. The top compression ring should be allowed at least 0.003-in. clearance in the grooves because of the excessive heat to which this ring is subjected. The second compression ring should have a clearance in the groove of about 0.002 in., and the third ring a clearance of about 0.0015 in.

Wrist Pins.—The wrist pins should be a press-fit in the pistons at normal room temperature or 70° F. If any wrist pin is too tight, the piston should be carefully reamed to provide the proper fit. In cool weather the wrist pins will be tighter than they are at normal room temperature because of the contraction of aluminum.

Assembling.—Before the engine assembling is started, an examination should be made of the cylinder pads on the crankcase and all burrs removed.

No. 1 piston should be replaced on the master rod in the same position it was in before removal—the name on boss facing front of the engine. The compression rings should be evenly spaced, that is, their openings 120° apart. After making certain that the cylinder barrel and piston are perfectly clean, oil the piston, rings, and barrel generously. Put gasket paste on the bottom of cylinder flanges. (NOTE.—Gasket paste should be insoluble in gasoline or oil and must not dry so as to require scraping. Blue Rock Gasket Paste, or its equivalent, is recommended.) After this is done, compress the piston rings by means of a ring clamp and put on No. 1 cylinder. Before the next cylinder is installed, No. 1 cylinder should be carefully and completely fastened down. The hold-down nuts should be tightened evenly all around with the wrench provided. The remaining cylinder should then be installed.

The push rods may now be placed in position, care being taken to see that they are put back in the same position they formerly were in. Tighten the intake hose clamp. Tighten intake manifold to the cylinder head. After the cylinder push rods and intake pipe are in place, the clearance at the valves should be adjusted, as specified on the engine name plate.

Before the oil sump is replaced, remove the oil screen and clean it. When the engine is assembled, a recheck should be made of all bolts and nuts in order to be sure that none have been overlooked.

Running-in after Top Overhaul.—It is highly desirable to operate the engine for at least two hours with a Storey Test Club or its equivalent. Flight propellers do not give sufficient air speed by the cylinder heads to provide adequate cooling on the ground. The two-hour running-in period will condition the new piston rings if any were installed.

If a new set of piston rings or a new cylinder barrel or barrels have been installed the engine should be flown at cruising speed for at least four hours before full-throttle operation is attempted. This flight running-in should not be made until after the recommended ground run.

TABLE OF CLEARANCES

(Revision of April 2, 1930)

No.		Minimum	Desired	Maximum	Replace
1	Breaker gap in Scintilla Magneto PN5D	0.012	0.000	0.015	0.016
2	Camshafts diametrical clearance in boss	0.003	0.0035	0.004	0.007
3	Camshaft end play	0.010	0.015	0.020	0.025
4	Crankshaft diametrical clearance, main bearings	0.00175	0.000	0.002	0.003
5	Crankshaft end play	0.010	0.012	0.014	0.025
6	Master rod bearing on crankpin	0.0018	0.002	0.0022	0.004
7	Master rod end play on crankpin	0.008	0.010	0.012	0.020
8	Magneto drive shaft diametrical clearance	0.003	0.0035	0.004	0.007
9	Magneto shaft end play	0.011	0.015	0.020	0.030
10	Oil retaining ring. Light press fit on crankshaft.				
11	Oil pump drive shaft diametrical clearance in body	0.0015	0.002	0.003	0.004
12	Oil pump drive shaft diametrical clearance in cover	0.0015	0.002	0.003	0.004
13	Oil pump gears diametrical clearance in body	0 001	0.003	0 005	0.006
14	Oil pump gears end play	0 001	0.002	0.0035	0.005
15	Oil pump gears diametrical on idler shaft	0 0012	0.0015	0.0027	0.004
16	Piston ring gap	0.012	0.012	0.015	0.025
17	Piston ring in groove No. 1 top (side play)	0.003	0.0035	0.004	0.006
18	Piston ring in groove No. 2 (side play)	0.002	0.0025	0.0025	0.005
19	Piston ring in groove No. 3 (side play)	0.002	0.002	0.0025	0.004
20	Piston ring in groove. Oil scavenger (side play)	0.001	0.0015	0.002	0.004
21	Piston pin in piston. Push fit at 68° F.				
22	Piston in cylinder at skirt	0.020	0.000	0.025	0.030

TABLE OF CLEARANCES—*Continued*

No.		Minimum	Desired	Maximum	Replace
23	Piston in cylinder at top..........	0.0345	0.000	0.0375	0.043
24	Piston in cylinder. Replace if over 0.005 out of round.				
25	Propeller hub diametrical clearance. Bearing $1\frac{1}{4}$ in. on big end, no bearing on small end...............	0.000	0.000	0.002	0 003
26	Key fit in hub..................	Fit	0.001L	0.002L	0.003L
27	Key fit in shaft. Light press fit.				
28	Link rod on lock pins forced feed. .	0.0008	0.001	0.0012	0.0025
29	Link rod side play forced feed.	0.006	0.0075	0.009	0.020
30	Link rod on piston pin............	0.0008	0.001	0.0012	0.003
31	Link rod on lock pin splash feed. . .	0.0015	0.002	0.0025	0.0035
32	Link rod side play splash feed. ...	0.012	0.018	0.024	0.000
33	Spark plug B. G. type (gap)......	0.014	0.015	0.016	0.000
34	Tappet roller on axles............	0.0015	0.0017	0.002	0.004
35	Tappet roller side play............	0.005	0.007	0.008	0.012
36	Tappet in tappet guide...........	0 0032	0.004	0.0048	0.008
37	Rocker arm axle in bushing.......	0.0015	0.0015	0.002	0.006
38	Rocker arm side play.............	0.010	0.012	0.014	0.030
39	Tappet clearance at valve cold engine (68° F.)..................	0.020	0.000	0.000	0.000
40	Valve diametrical clearance exhaust	0.0025	0.003	0.004	0.000
41	Valve diametrical clearance intake.	0.0025	0.003	0.004	0.000
42	Lock pins in master rod...........	0.0002T	0 0003T	0.0004T	0.000

CHAPTER XIII

THE PACKARD DIESEL ENGINE *

The Packard Diesel Aircraft Engine is a nine-cylinder, fixed radial, air-cooled engine operating on the four-stroke Diesel cycle. The outstanding advantage of the engine lies in its ability to operate upon low-grade fuel. Operating upon domestic furnace oil the engine has the advantage of reduced fuel cost and fuel consumption, and the fire hazard is practically eliminated. The principle upon which the engine operates makes possible the combustion of the fuel without electric ignition. Therefore, radio interference is not encountered.

SPECIFICATIONS

Type.—Air-cooled, static radial.
Rated H.P.— 225 at 1950 r.p.m.
Number of Cylinders.- Nine.
Compression Ratio.—16 : 1.
Bore.—4$\frac{11}{16}$ in.
Stroke.—6 in.
Piston Displacements.— 980 cu. in. (approx.).
Overall Diameter.— Slightly over 45 in.
Type of Piston.—Aluminum alloy.
Ignition.—Compression heat.
Number of Valves per Cylinder.—One.
Crankcase.— One-piece magnesium alloy casting.
Crankshaft.—Conventional split type. Counterbalanced.
Connecting Rods.—Conventional master rod and link rods.
Valve Mechanism.—Conventional overhead, push rod, and rocker arm.
Cylinders.— Closed end, steel.
Lubrication.—Force feed, dry sump.
Oil Pressure.—60 lb.
Weight.—510 lb.; 2.26 lb. per h.p.

THE DIESEL CYCLE

Though it requires four strokes or two revolutions to complete the cycle in the four-stroke cycle Packard Diesel Engine, there is a difference

* This section was arranged from data kindly furnished by the Society of Automotive Engineers.

in the events of the cycle, when compared with the four events of the conventional, carbureted engine employing the Otto cycle. During the

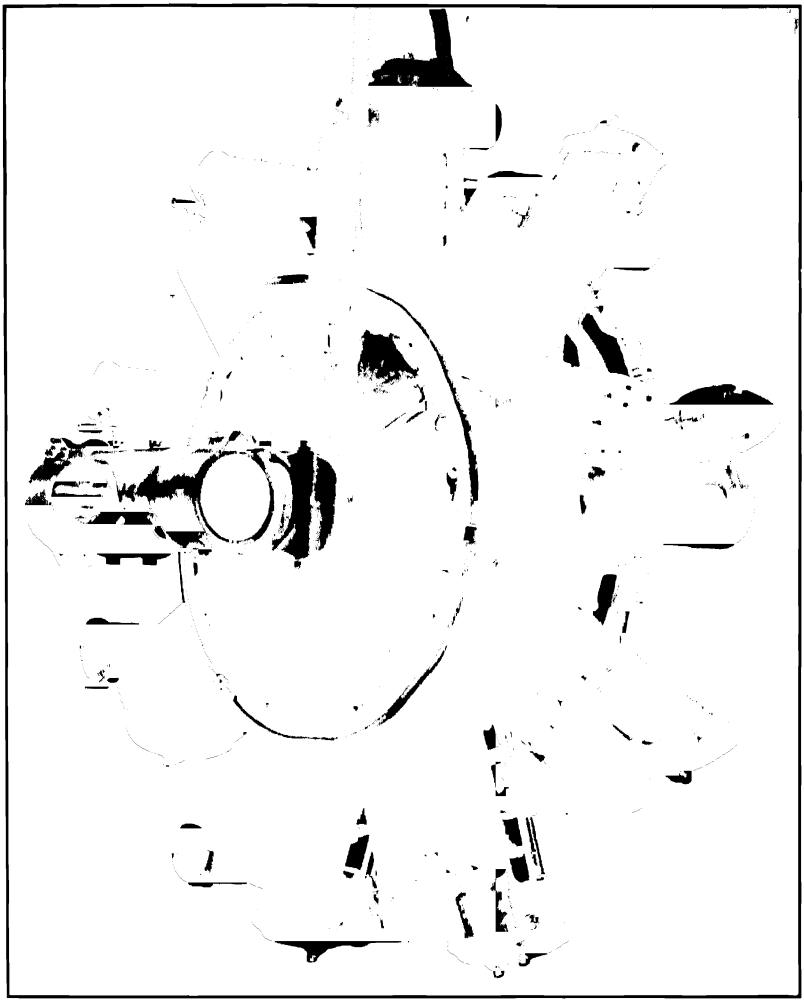


FIG. 94—The Packard Diesel Engine.

Note hoist hook attached to hoop which is one of two hoops holding cylinders to crankcase as well as creating an initial stress in the crankcase

first stroke, air alone is drawn into the cylinder at atmospheric temperature and pressure. The valve closes after bottom center (a single valve is employed) at approximately the same timing as in carbureted engines,

and the piston ascends upon the compression stroke. The compression ratio of the engine being 16 to 1, the pure air is compressed to a very high degree (about 500 lb. to the sq. in.), resulting in the compressed air attaining a temperature of approximately 1000° F. This temperature is far above the spontaneous ignition temperature of fuel oil. Therefore, injection of fuel at approximately 45 degrees before top center, corresponding to the same point at which electric ignition occurs in the carbureted engine, results in combustion. When the piston is almost at top center, a cutting off of fuel injection takes place. This timing of fuel injection and cut-off permits the pressure in the cylinder to rise at a slow rate until a maximum pressure of about 1200 lb. to the sq. in. is reached with full fuel injection, or in other words, with full throttle.

The third stroke is the same as in the carbureted engine with the piston being forced outward from the expansion of the gas, the valve opening at approximately 45 degrees before bottom center to start the fourth event or exhaust. The single valve remains open to scavenge the cylinder during the exhaust stroke, and, as the single valve serves as an inlet as well as an exhaust, the valve remains open when top center is reached, for a new cycle of operation is again started with the suction stroke. During the 720 degrees required to complete the cycle, the valve opens once, which is about 45 degrees before bottom center when it is serving as an exhaust valve, and the valve remains open about 440 degrees to allow for the exhaust and intake events, and is closed about 280 degrees to allow for compression, combustion, and expansion.

FUEL REQUIREMENTS

The extremely high temperature of the compressed air within the cylinder during the compression stroke permits the use of fuel having a high ignition temperature. Fuel which closely approaches crude petroleum oil is successfully used and accounts for the reduced cost of fuel, for the Diesel fuel is not subjected to the expensive process necessary to produce highly refined gasoline.

The Packard Diesel will operate on many different fuels, but the most satisfactory has been found to be domestic furnace-oil, having a gravity of approximately 37 degrees Baumé, or a specific gravity of about 0.84. This grade of oil is a refined product, and is almost entirely free from dirt and impurities. This oil has a sufficiently low pour-point to allow it to flow freely at low temperatures.

While gasoline may be used for fuel in the Packard Diesel, its use is not recommended under any circumstances. The outstanding advantage of the Diesel for aircraft is lost when gasoline is used, because of the

return of the fire hazard. Also gasoline has no lubricating qualities to provide lubrication for the fuel pumps, whereas fuel oil has sufficient lubricating qualities to cause the plungers of the fuel pumps to work satisfactorily.

While this disadvantage of gasoline could be overcome by the addition of lubricating oil, satisfactory engine performance will not result because of the fuel pumps having been proportioned to handle fuel oil which has approximately 23 per cent excess in heat value over gasoline on a volumetric basis.

FUEL INJECTION

Fuel injection is accomplished by nine separate pumps, one to each cylinder of the engine. These pumps and their injector nozzles are

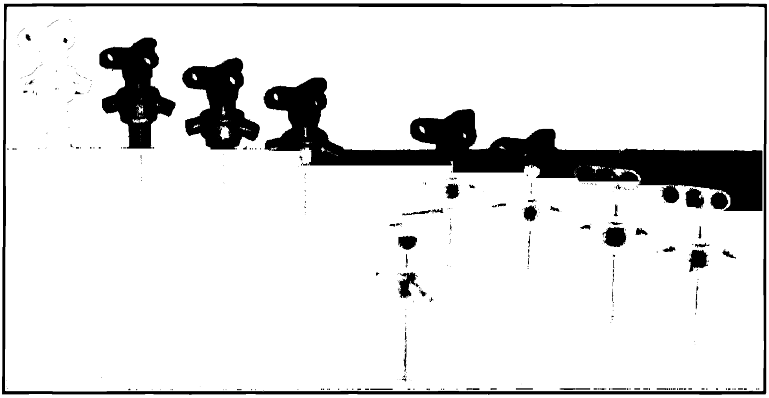


FIG. 95.—The Nine Combination Fuel-pump and Nozzle Units.

shown in Fig. 95. It is the duty of these pumps to force the fuel oil through the injector nozzles at the proper time and at a speed which will insure sufficient fuel injection during the available time, which is as little as 0.004 second. The pumps are of a simple plunger type, fed from an oil line which extends around the engine. This oil line is kept full by an oil pump which draws the fuel from the supply tank. The body of the fuel pump comprises a machined alloy steel forging fitted with a bronze cylinder pressed into place. The pump cylinder bore is finished to the highest possible degree of accuracy. The plunger of the pump is made of heat-treated steel, and has a mushroom head engaging a T-slot in a cross head, which, in turn, contacts with the fuel pump tappet. The return of the pump plunger, after its working stroke, is accomplished by a compression spring which surrounds the

fuel pump cylinder. After passing through a fine-mesh screen fuel enters the pump through ports provided in the fuel pump cylinder. These screens have sufficient area to prevent clogging during several hundred hours of service. Between the body of the fuel pump and the nozzle body, there is a ball check valve to prevent gases, from the

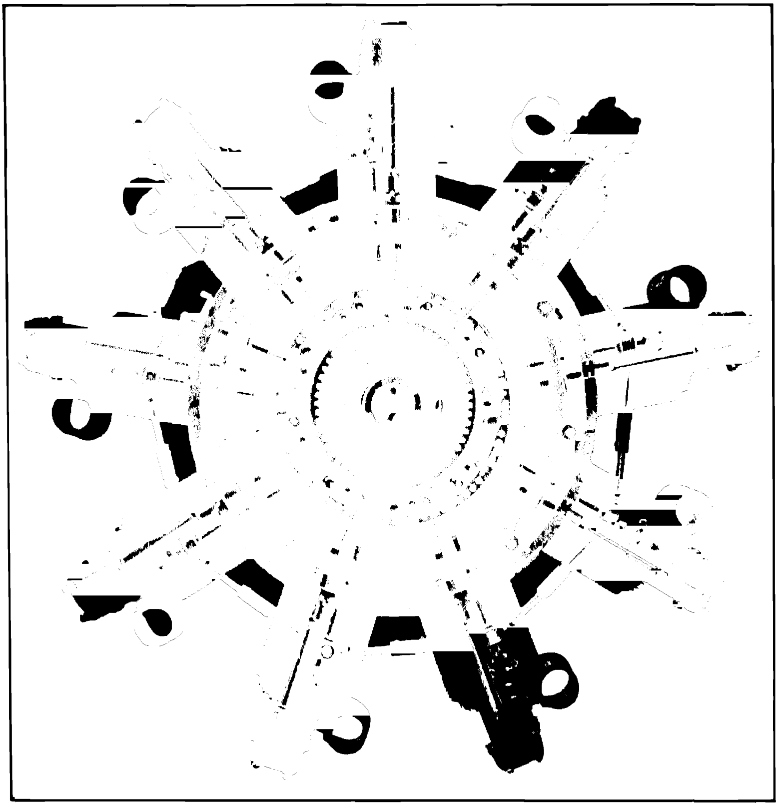


FIG. 96.—Rear View of the Packard Diesel with Complete Valve and Fuel Mechanism Exposed.

combustion chamber, from entering the fuel pump cylinder, yet permitting the fuel to flow from the pump to the nozzle.

The fuel pump and valve push rods are operated by four lobe cams driven at $\frac{1}{8}$ crankshaft speed in the opposite direction from the rotation of the crankshaft. The individual fuel pumps and single valve of each cylinder are operated by rocker arms which make contact with their respective cams. The valve rocker arms and fuel pump rocker arms

make contact with short push rods which are ball-ended, and make contact with plungers at their outer end. These plungers are fitted in duralumin guides radially arranged and bolted to machined surfaces on the outside of the crankcase. See Fig. 96.

The fuel pump push rods near their inner ends are connected by

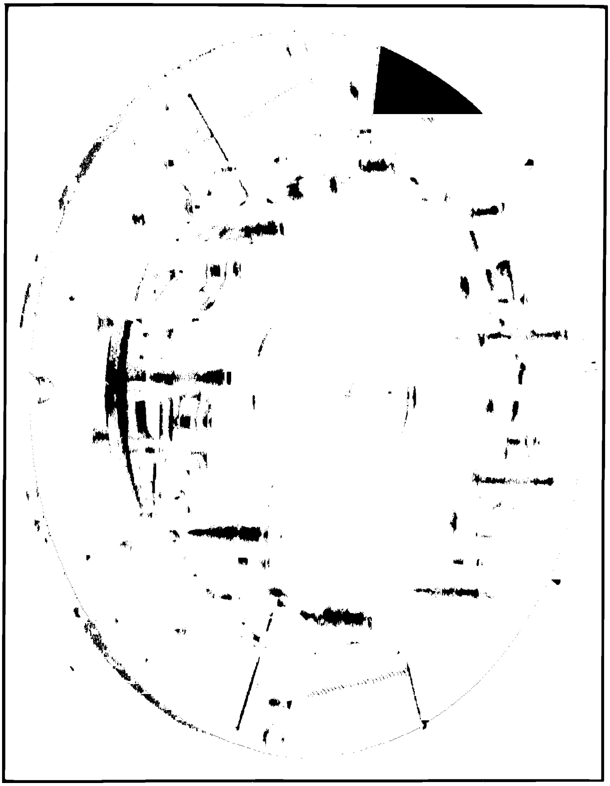


FIG. 97 —Valve and Fuel-pump Tappet Assembly, Diaphragm, and Control Ring of the Packard Diesel Engine.

linkage to a circular control ring mounted in a groove on a diaphragm. The movement of the control ring is accomplished by an external lever connected to a control in the cockpit of the airplane through which the speed of the engine is regulated. By this means a regulation of fuel injection is accomplished through altering the effective stroke of the fuel pump plunger.

At approximately 45 degrees before top center during the compression

stroke of the engine, the fuel-pump tappet starts to rise, forcing the pump plunger upward. When the pump plunger has passed the inlet port of the fuel-pump, fuel which has been trapped in the fuel-pump cylinder is compressed and forced out through the nozzle in a finely atomized spray. The amount of fuel injected depends upon the length of the stroke of the fuel-pump plunger above the cut-off position, which is the point at which the inlet port to the fuel-pump is covered by the plunger. The amount of stroke above this cut-off position is determined by the position of the fuel-pump push-rod in the groove formed in the fuel-pump rocker arm, which depends upon the position of the control ring carrying the small connecting rods attached to the push-rods. This control is rotated through a small arc by means of a tapered roller engaging in a slotted yoke which is riveted to the control ring. The tapered roller is mounted on a short lever which is splined to the control shaft, and this shaft is journaled to the shaft to which the pilot's control is connected. See Fig. 97.

TURBULENCE

The ideal strived for in both the carbureted engine and Diesel engine is a homogeneous mixture of fuel and air. In both engines the

FIG. 98.—The Single Valve and Multiple-type Valve Spring of the Packard Diesel Engine.

time available for obtaining such a mixture is extremely small at high speeds. In a carbureted engine the mixture of fuel and air takes place in the carburetor, inlet manifold, and in the cylinder during the inlet and compression strokes, but in the Diesel engine no fuel is drawn into the cylinder with the air admission, the fuel being injected about the time combustion is desired. Therefore, there is no opportunity to

prepare a mixture of fuel and air prior to combustion to the extent that is afforded in the carbureted engine. In the Diesel Engine the only opportunity for mixing the fuel and air is during the short interval of fuel injection. To inject sprayed fuel into the combustion chamber is difficult in the time available, and a penetration of a half inch is the average. In the Packard Diesel, mixture of the fuel and air is accomplished by creating a whirling motion to the entering air, so that the air will sweep past the nozzle and mix with the injected fuel. This created

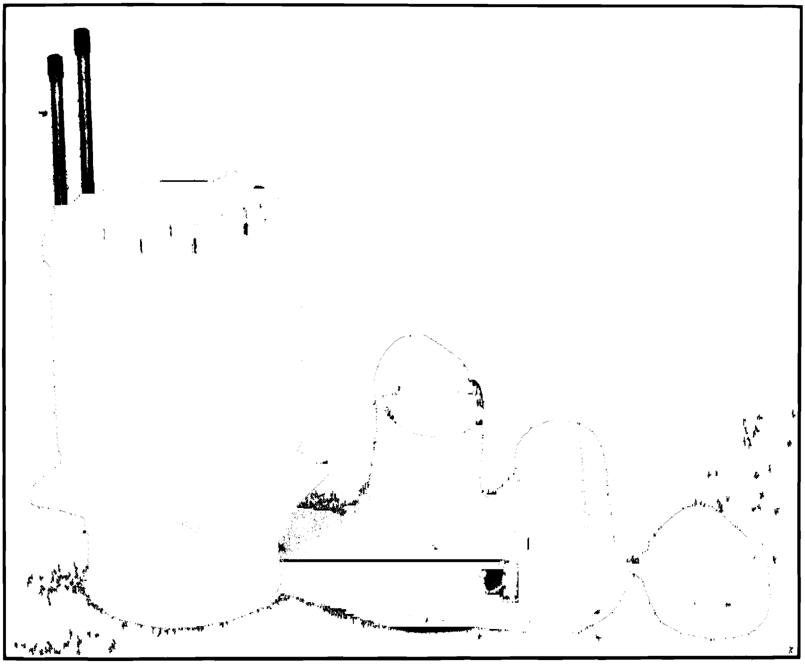


FIG 99 The Cylinder and Cylinder-head Carrying Oval Support, and the Housing for Valve Operating Mechanism.

turbulence is accomplished by shaping the inlet port in the form of a flattened Venturi arranged tangentially to the cylinder bore. When viewing the cylinder from above, the port and valve locations are arranged so that turbulence is created in a counter-clockwise direction. The large diameter, which a single valve allows, assists very materially in obtaining a full volume of air into the cylinder, and also lowers resistance to the speeded-up air-flow as well as permitting a wider Venturi passage than could be provided with a smaller valve. This

results in an arrangement which directs the air into the cylinder at the smallest angle to the horizontal.

CYLINDERS

The Diesel principle permits the use of cylinders somewhat different from cylinders used on the carbureted engine, for though the steel barrel and fins are conventional, the cylinder head bears little likeness to the cylinder heads on the carbureted engine. The superior thermal

FIG. 100 —The Front and Rear of Cylinders Assembled, with Heads Showing Rocker Arm, Air Shutter Operating Mechanism, and Combination Fuel-pump and Nozzle Unit

efficiency of the Diesel when compared with the carbureted engine permits a simple form of closed-end cylinder instead of the conventional screwed-on or bolted-on aluminum head found on the carbureted engine. The closed end form of cylinder is possible because of the lower heat losses to the cylinder walls in the Diesel.

In Fig. 99 is shown the cylinder design and the light aluminum

cylinder head which supports the valve-operating mechanism as well as forms the combined inlet and exhaust port.

The ability of the Packard Diesel to function satisfactorily with a single valve for both inlet and exhaust simplifies the design of the cylinder head, and lightens the cylinder head without detracting from its strength. The employment of a single valve, while contributing toward weight saving and simplicity, also gives the advantage of greater dependability because of the valve's operating at a considerably lower temperature than the conventional exhaust valve. This lower temperature is made possible by the cooling effect of the entering air when air admission follows the exhaust event.

The aluminum alloy cylinder-head castings are secured to the top of the cylinders by ten studs which serve as heat conductors for transferring heat from the upper surface of the cylinders to the radiating fins on the cylinder head.

It will be noted in Figs. 99 and 100 that the cylinder heads are fitted with tubes having shutter valves at the front ports. These shutter valves are operated by fore-and-aft connecting rods, which in turn are connected to the air-valve push-rod tube by ball-joints. These tubes are fitted at their inner ends with ball-jointed levers engaging sockets which are riveted to a control ring supported from the crankcase-mounting bosses. This control ring is operated by means of a cam in conjunction with the throttle, so that for idling purposes the front ports may be closed and all air drawn back through the exhaust manifold. The system just described is not essential to the operation of the engine. Yet it assists materially in obtaining steady engine speed as low as 250 r.p.m., which has been a problem in Diesel engines.

PISTONS

The pistons are aluminum alloy of conventional design with the exception of the piston head which is provided with an eccentrically located pocket, as shown in Fig. 101. This pocket in the head of the piston, in conjunction with the inlet port and valve arrangement described, promotes the high degree of turbulence, which makes possible efficient operation at high engine speeds.

Each piston is fitted with a conventional type of full-floating wrist pin with the customary aluminum plugs expanded into each end of the wrist pin to prevent cylinder wall scoring. An oil control ring and two compression rings are fitted to each piston, the oil control ring being placed below the piston pin.

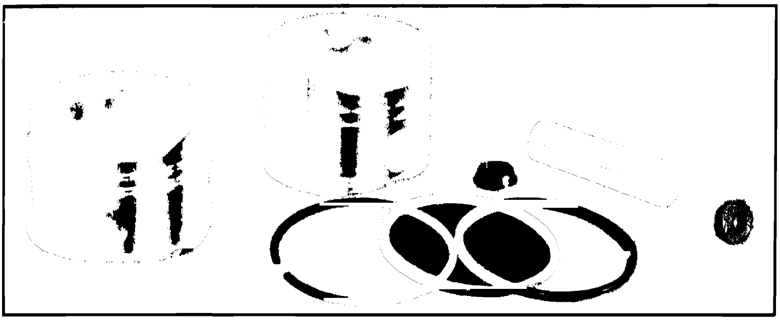


FIG. 101.—Pistons, Rings, and a Piston-pin of the Packard Diesel.

CRANKSHAFT AND CONNECTING RODS

The crankshaft, master rod, and link rods follow conventional practice in radial engine design, the master rod being solid, and the crankshaft being the split type. The counterweights attached to the crankshaft differ from customary design in that they are flexibly

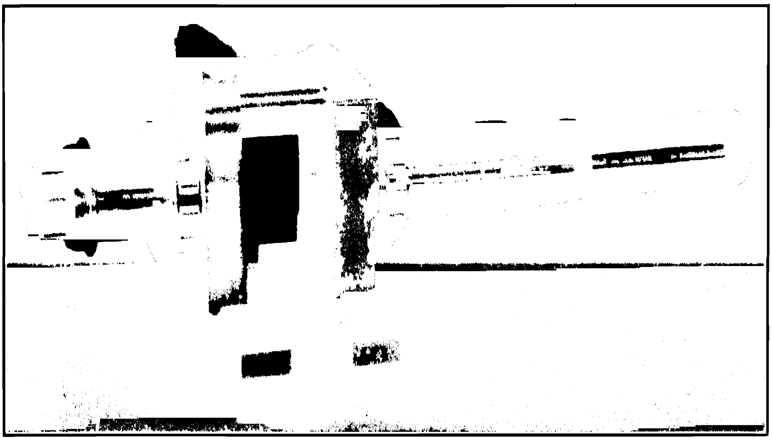


FIG. 102.—The Two-piece Crankshaft with Flexibly Mounted Counterweights.

mounted. Instead of being rigidly secured to the crankshaft, the counterweights are pivoted to the crank-cheeks and are located between powerful compression springs. This construction permits the counterweights to lag behind slightly when the crankshaft is suddenly accelerated, so that the peak cylinder pressure is expended before the counterweights are again solidly driven by the crankshaft. This arrangement

is employed so that comparatively light parts may be used in the engine. The shock-loading, which results from high combustion pressures in the Diesel, calls for a cushioning of the major parts, to prevent the use of parts of greater strength and increased weight. This shock-absorbing feature of the crankshaft counterweights, combined with a similar shock-absorbing arrangement at the propeller hub, contributes considerably toward the reduced weight of the Packard Diesel in comparison with previously built Diesels. See Fig. 102.

CRANKCASE

Departures from conventional radial engine design and construction in order to effect a weight reduction with increased strength have been

FIG. 103.—The One-piece Crankcase of the Packard Diesel.

followed in the Packard Diesel. Particularly the crankcase reflects the study in weight economies. Weighing but 34 lb., the crankcase is novel in respect to the method in which the cylinders are secured to it. The conventional practice in air-cooled, radial engine designing is to fasten the cylinders to the crankcase by studs screwed into the crankcase flange and projecting through the cylinder flanges against which the retaining nuts seat. The tension stresses resulting from combustion

loads in this arrangement are carried through the crankcase walls to the crankshaft main bearing anchorage. While this construction compels heavy crankcase construction on the carbureted engine, the same design would necessitate extremely heavy crankcase sections to withstand the stresses from shock-loading in the Diesel engine. The Packard Diesel crankcase has two circular hoops of alloy steel encircling the cylinder flanges in contact with the crankcase at the front and rear of the engine. These hoops are contracted by turnbuckles, which results in an initial stress being set up in these hoops which is in excess of any operating stress created by combustion. This arrangement makes it impossible to transfer tension loads from the cylinders to the crankcase. See Fig. 94.

The crankcase is a one-piece, magnesium-alloy casting supporting by means of a forged-steel container a deep-groove ball bearing at the front end to take radial load and propeller thrust. Ahead of the front crankshaft-cheek a roller bearing is mounted, as in conventional practice. The crankcase is closed at the rear end by a cover casting, carrying the required accessories: namely, the oil and fuel circulating pumps, starter, generator, and tachometer drives. See Fig. 103.

LUBRICATION SYSTEM

The lubrication system follows the conventional arrangement common to radial aircraft engines, and comprises an oil pump, an external oil tank, scavenger oil pump, and pressure relief valve, operating on the dry-sump principle. A simplification of the system is found through the absence of oil pipes inside the engine and a dispensing with drilled passages in the crankcase. A pipe leading from the bottom of the oil tank conveys the oil to the oil pump housing where the oil passes through a screen. The oil is picked up by the oil pump and forced through the main connection to the engine by way of a pressure-relief valve set to about 60 lb. per sq. in. The main connection to the engine is effected by means of a hollow rocker-arm pin opposite No. 4 cylinder. At the inboard end of this pin a groove is arranged in the diaphragm, and a radial hole is drilled to convey the oil to a socket connection, which receives one end of what appears to be a hollow dumb-bell. The other end of this swinging connection engages a socket in a forged ring floating on the hub of the cam. The oil passes through a groove in this ring to several holes in the cam and then on through drilled passages to the hollow extension of the rear half of the crankshaft. The object of the dumb-bell connection is to allow the oil ring

to float concentrically on the cam without being restrained in any direction by the connecting member.

A hole is drilled in the rear crankshaft cheek which is in line with a hole communicating with the interior of the crankpin, which is drilled out for lightness and also to serve as an oil reservoir. The crankpin is drilled for lubricating the connecting rod bearing. The connecting rod bearing is formed of two flanged bushings mounted end to end with a small clearance between them. Oil flows through this clearance space into slots machined in the master connecting rod big-end bore and then on through small holes drilled at an angle to convey oil under pressure to the link-rod-pin bushings. The counterweight-pin bushings are lubricated by oil passages drilled through both crank-cheeks.

The rocker-arm shafts, fuel and valve rocker-arms, rocker-arm roller-pins, and roller bushings are lubricated by drilled passages, the crankcase cover also being drilled with passages to provide lubrication to the accessory shafts and their bearings.

The return of the oil collected in the bottom of the crankcase to the oil-tank is accomplished by the usual scavenger pump. The lubrication of the pistons, cylinder walls, and piston pins is accomplished by the oil spray in the crankcase, as in all other types of aircraft engines. Lubrication of the external valve-rocker-arm bearings depends upon a periodic use of a pressure gun, as in common practice with overhead valve action.

STARTING AND STOPPING THE ENGINE

A standard inertia starter is employed for starting the engine. The fly wheel of the starter is rotated either by hand or by means of an electric motor as in other aircraft engines. The usual process of choking or priming common to the carbureted engine is not required in the Diesel. The throttle of the Diesel is held wide open for starting, and no special fuel or heating is required to obtain a practically instantaneous start during normal weather conditions. Starting a Diesel engine at temperatures below zero is a problem which was solved in the Packard Diesel by employing glow-plugs to furnish the necessary heat for starting. These glow-plugs comprise a heating element of sufficient heat-giving qualities to start the engine at any temperature in which it is possible to rotate the engine with the starter.

Stopping the engine is accomplished merely by closing the throttle beyond a spring stop. This extra motion of the throttle restricts the stroke of the fuel-pumps until the plungers barely ride higher than the pump inlet-port, resulting in a fuel cut-off to the nozzles. By closing

the throttle completely, the engine may be stopped instantly while operating at high temperatures without any kicking-back.

THE ENGINE DURING FLIGHT

To obtain complete combustion and the low specific fuel-consumption possible with the Diesel cycle, it is necessary to provide an excess of air over that required to combine with the fuel. This excess of air in many cases may amount to 25 per cent of the air drawn into the cylinder during the inlet stroke. However, when additional power is desirable, as in the take-off and in emergencies, it is permissible to inject an extra amount of fuel into the cylinders to combine with most of this excess air. Combustion is not so complete with this throttle opening as it is under normal conditions, and while the engine smokes, a gain in power is obtained at but a slight sacrifice in fuel economy. This "overloading" condition may be utilized until the emergency is passed, the engine may then be throttled so that the normal excess of air will result in economical fuel-consumption.

As the altitude increases, the engine speed increases with a set throttle position. This characteristic of the Diesel, which is the opposite of carbureted engine performance, is due to the fact that a predetermined amount of fuel is injected into each cylinder, and this fuel needs for its complete combustion a certain weight of oxygen. The density of the air decreasing with altitude results in a given weight of oxygen being contained in a larger volume of air at higher altitude. It is obvious that a position of the throttle which would cause the fuel to combine with only half the available oxygen near sea-level would give the equivalent of full-throttle operation at approximately 18,000 ft. This Diesel characteristic relieves the pilot of the task of studying altitude effects and making altitude adjustments required on the carbureted engine, for the Diesel automatically adjusts itself to burn efficiently whatever fuel is being injected. Therefore, the engine tends always to give the most economical result.

CHAPTER XIV

PROPELLERS *

The modern metal propellers for aircraft engines constitute an advancement in propeller design and construction which has been little short of revolutionary. The lack of mechanical strength of non-metal propellers has been a source of grave concern to aeronautical engineers, and, particularly, when high-powered single-engine planes had to place dependence in the problematical and questionable strength of wood or composition blades. The non-metal propeller situation was further aggravated when commercial transport service called for flying through inclement weather. Rain, hail, snow, and sleet played havoc with the wooden propeller, often resulting in propeller failure and disastrous forced landings.

Flight tests of metal propellers have repeatedly shown their superiority over other types. Propeller efficiency is of outstanding importance, and the superior efficiency of the modern metal propeller coupled with its many other advantages indicates that the long-sought practical, metal propeller is a reality.

The propellers built by the Hamilton Standard Propeller Corporation have blades made from a special aluminum alloy, drop-forged in a die to approximate size. They have a tensile strength of 55,000 lb. per sq. in. The hub is made of chrome vanadium steel heat treated to a tensile strength of 130,000 lb. per sq. in. These propellers are made with separate blades, which can be attached to two-, three-, or four-way hubs. This is advantageous, for the operator can so set the pitch of the propeller as to take advantage of whatever feature of performance is most important. For example, it may be desirable to get out of a small field even at the expense of the speed of the airplane. In this case the propeller should be set at a low pitch, allowing the engine to turn up fast on the take-off. The plane will then get off the ground in a short distance. On the other hand, it may be desirable to economize on fuel. For this, the pitch of the propeller should be set at a high angle

* The data of this section were kindly furnished by Hamilton Standard Propeller Corporation.

and the engine held down to a low r.p.m. at full throttle. This setting will give the greatest economy of fuel.

METHOD OF ADJUSTING THE PITCH

The inner, or hub ends of the blades are made to fit in the hub sockets, with a clearance of 0.003 to 0.005 in., thereby making it possible to adjust the blades of the propeller, to the engine in service, without removing it from the engine. The blades are clamped rigidly in place by means of clamping rings at the outer extremities of the hub sockets.

To change the pitch of the propeller, the cotter pin must be removed

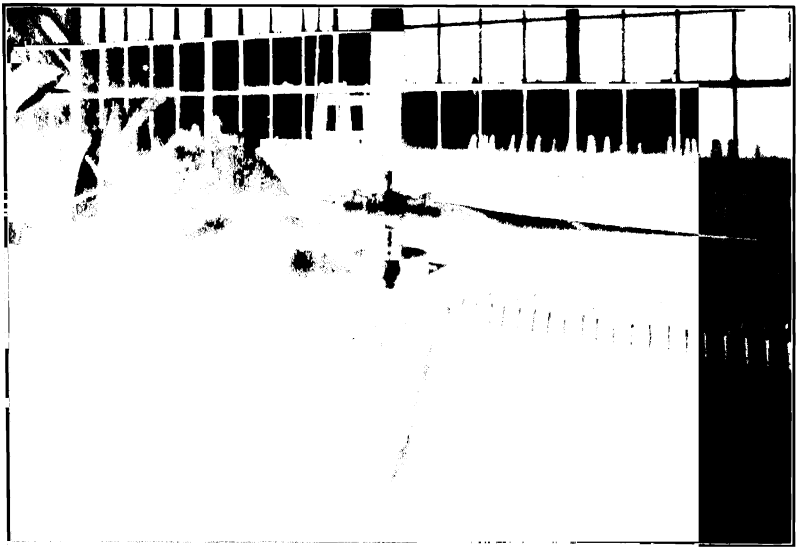


FIG. 104.—Checking Blade Angle by the Use of a Protractor and Checking Plate.

from the bolt in the clamping ring, and the nut in this bolt should be backed off until the ring is loose. The propeller blade may be tapped near the hub with either a wooden or rubber mallet until the desired pitch angle is shown on the scale on the end of the hub. Great care must be exercised to insure that each blade of a given propeller is set at identically the same angle.

After adjusting the pitch, the clamping ring should be pressed outward by hand against the shoulder on the end of the hub, and the bolt in the clamping ring again tightened, and the cotter pin replaced. Since the position of the bolt in the clamping ring affects the balance of the propeller, care should be taken, after adjusting, to see that it is

in the original position. This position is made certain by moving the clamp rings until the arrows thereon are in a direct line with the arrows on the hub.

In assembling the propeller on the engine shaft it is necessary that the bore of the taper be clean and free from any dirt and also that the shaft end of the engine be free from dirt and burrs. The retaining nut should be pulled up very tight when the propeller is assembled on the engine shaft.

The best method for setting the blade angle is by the use of a protractor and a checking plate. If no checking plate is available, the scale on the end of the hub should be used for setting the pitch. See Fig. 104.

The propeller setting usually is specified as the blade angle at a point 42 in. from the axis. This rule cannot be applied for very small or very large propellers, and the angle setting, as well as the radius at which it is to be measured, is specified.

When it is desired to change the r.p.m. of the engine at full throttle by adjusting the pitch of the propeller, the following general rule may be applied: The engine will slow down 60 r.p.m. for each degree of increase in pitch and will speed up 60 r.p.m. for each degree of decrease in pitch.

REPLACEMENT OF DAMAGED BLADES

A decided advantage of the detachable blade feature is that, when only one blade is damaged, the good blade can be matched at the factory with a new blade. The blades are made interchangeable so that a damaged blade can be replaced with a new one of the same design from stock. Because of this, where one operator is flying several planes, the number of spare blades on hand may be kept to a minimum, especially as only one blade is damaged in so great a number of cases. It should be borne in mind, however, that blades which have been worn by long use will not balance perfectly with new blades, so that it is often desirable to return such blades to the factory for matching with new blades. Where an operator is using a number of airplanes equipped with similar engines, an additional advantage is that the same propeller can frequently be used on the different planes by setting the pitch to the required angle. For example, the same propeller can be used on either the 300 h.p. Wright J-6 or the Pratt & Whitney Wasp Junior by changing the pitch to suit the variations of power and r.p.m. of the two engines. And so the supply of extra propellers may be reduced to a minimum, and a greater percentage of flying equipment kept in service.

SPECIAL BOLTS FOR CLAMPING RINGS

The bolts used in the clamping rings are provided with a fillet to prevent localized stress at the shoulder. These bolts are specially made from heat-treated alloy steel and should not be replaced with commercial bolts, because the commercial bolts do not have the necessary strength.

The filister head screws serve to hold the two halves of the hub

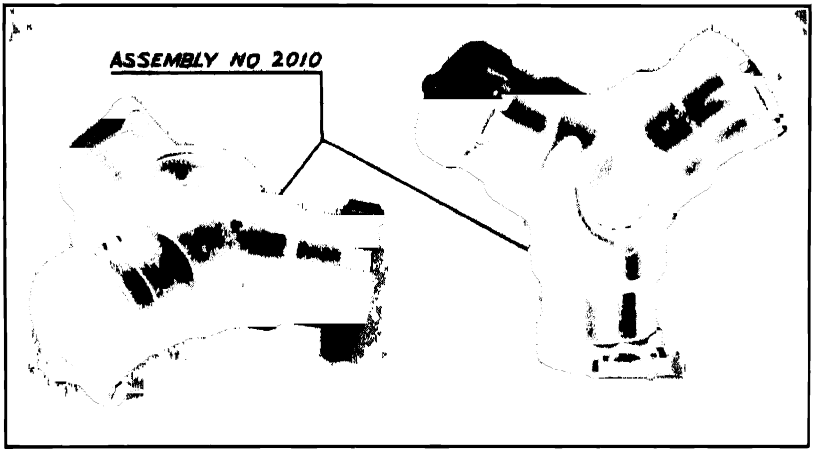


Fig. 105.—Three-blade Hubs Assembled.

together during assembly but are not subjected to any load after the propeller is assembled on the engine shaft.

SHOULDERS ON BLADE ENDS

The shoulders on the blade ends are so designed that the shearing strength and the crushing strength are equal and, though nearly so, are not quite as great as the tensile strength of the smallest section of the blade end. Tensile tests on these blade ends show that they fail at 320,000-lb. load for the No. 1 size. This corresponds to a factor of safety of approximately 5 for the standard 10-ft. propeller when turning at 1800 r.p.m.

The No. 1 size of hub can be used on engines up to, and including, the Wright J-6 and Pratt & Whitney Wasp. On larger engines, such as the Pratt & Whitney Hornet and the Wright Cyclone, the No. 1½ size is used for two-blade propellers; for three-blade propellers the No. 1 or No. 1½ sizes can be used. The No. 0 size hub is used for engines

up to 125 h.p., including the Warner, Kinner, OX5, Le Blond, Gipsy, etc.

The No. 2 size hub is used for geared engines requiring propellers of large diameter.

STRAIGHTENING OF PROPELLER BLADES

Under no circumstances should welding be undertaken. The application of excessive heat will completely destroy the strength of the alloy, causing it to become weaker than common aluminum. In case blades are damaged they should be returned to the factory for repairs, because they must be annealed and re-heat treated. All repaired blades are carefully etched for hair cracks before leaving the factory.

Fig. 106.—Blade End in a Three-way Hub.

BALANCE OF THE PROPELLER

The balance of the propeller is very important, because a small amount of unbalance will cause harmful vibrations in the engine and in the airplane structure. Unbalance may be either static or dynamic. The static balance may be perfect even though the dynamic unbalance exists; and *vice versa*.

STATIC BALANCE OF THE PROPELLER

The static balance can be checked by mounting the propeller on a mandrel passing through the hub, the mandrel being laid on suitable knife edges. The propeller should remain stationary in any position, without persistent motion. In adjusting the static balance the propeller is placed on knife edges with the blades in a horizontal position. If the propeller is out of balance, the light blade is removed from the hub and a small amount of heavy metal is placed in the bore of the blade end. All the blades are carefully checked at the factory against

a master blade, and when they leave the factory they are interchangeable as to balance. After extensive use a slight amount of wear will occur on the blades, and so, when a bent blade is replaced with a new one, there is a possibility of a slight amount of unbalance. While this never will be great enough to damage the engine or the plane, it is desirable that the propeller be perfectly balanced. If a slight unbalance is detected, it can be corrected by applying a coat of varnish or enamel to the light blade until the blades are balanced when in the horizontal position.

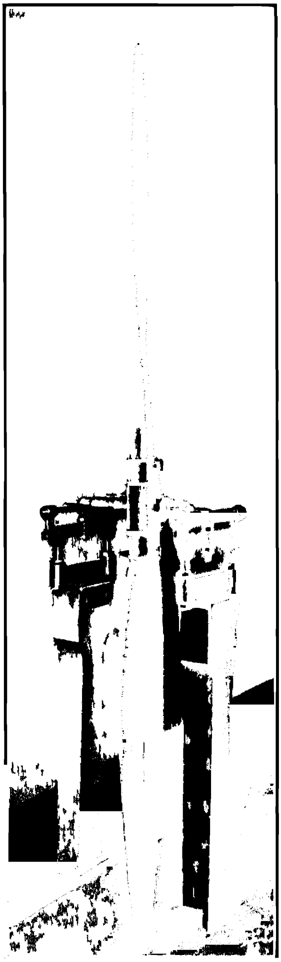


FIG. 107.—Vertical Balance of Propeller.

STATIC BALANCE WITH THE BLADES IN THE VERTICAL POSITION

Perfect balance with the blades in the vertical position can be secured by adjusting the clamping rings. The eccentric weight of the bolts in these rings is sufficient to correct the unbalance, when the rings are shifted to one side. The bolt should always be moved toward the light side of the propeller until perfect balance is secured.

DYNAMIC BALANCE OF THE PROPELLER

The running, or dynamic, balance of the propeller is ordinarily roughly checked by testing the "track" of the propeller. The propeller is mounted on the engine or on a suitable mandrel, and the blades are swung through an arc of 180 degrees. Both blades should pass through exactly the same path, and the amount by which they fail to do so is the "error in track."

The propellers are carefully tracked at the factory and cannot be put out of track at the time of installation, because all detachable parts are mounted on accurately machined surfaces.

In the factory an additional method of checking the dynamic balance

of propellers is provided by the type of design in which the centers of gravity of all the cross sections lie in the same straight line which is an extension of the axis of the hub ferrule. This feature makes it possible to check the dynamic balance of the propellers more accurately than is possible in any other type or design. In addition to the unbalance resulting from the centrifugal forces, it is possible also to have an unbalance due to air pressure. Thus, if the angle of one blade were set very much greater than the angle of the other, the air pressure would be greater on the blade with the higher angle, and vibration would result. For this reason the propellers are set very accurately at the factory, the two opposite blades being set to correspond to within $\frac{1}{10}$ of 1 degree. It is not always possible to set these blades accurately in the

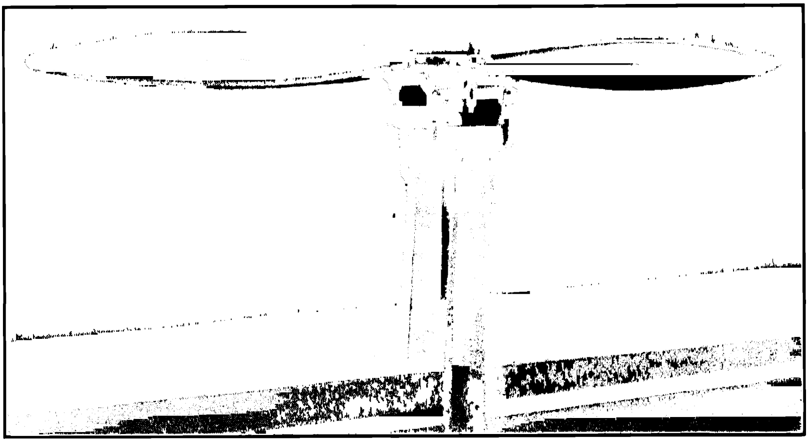


FIG. 108—Horizontal Balance of Propeller.

field, but it is recommended that an effort be made to keep the angle of the two blades alike within $\frac{2}{10}$ of 1 degree.

CARE OF PROPELLER BLADES

Whenever there is any sign of pitting on the leading edge of the blade, it must be attended to immediately. If the pitting is at all bad, the rough edges should be smoothed with a fine file, the whole leading edge smoothed down with emery cloth and finished with crocus cloth. However, the file should be avoided if possible and be used only when the pitting is so extensive as to make its use necessary. Occasionally, when severe pitting occurs, it may be necessary to remove so much material that the propeller becomes unbalanced. This condition must be watched for and be corrected.

Ordinarily, propellers are furnished bright—that is, without either paint or protective coating. The best protection for the metal is a thin coat of oil, to be applied by wiping the blades with an oily rag, and this should be done after the tips have been touched up with the emery and crocus cloths to remove roughness.

RECOMMENDED PRACTICE FOR INSPECTION, BALANCING, AND CARE OF HAMILTON STANDARD PROPELLERS

The following suggestions are offered to enable operators to secure maximum efficiency from their propellers. Each field or large operator should be provided with a first-class checking plate, protractor, and balancing stand in order to service propellers satisfactorily. The following points should be observed by users of Hamilton Standard Propellers:

In assembling the propellers, the blades should be pulled out against the shoulders before clamping them into position, as they will not properly balance when placed on the stand unless the blades are firmly pulled out against the retaining shoulders. It is true that they would be pulled out by the centrifugal force as soon as they are put in service, but it is impossible to check the balance unless the blades are in the proper position.

A second point on which some confusion exists is the location of the clamping rings. These rings can be adjusted around the hub barrel to obtain perfect balance with the blades in a vertical position. These blades are adjusted at the factory for perfect vertical balance, and an arrow is marked on the clamping ring and another arrow on the hub. These arrows should line up to secure the balance of the propeller. In re-balancing the propeller after considerable service, or in placing new blades in the hub, it will be necessary to adjust these clamping rings slightly to secure a perfect balance. The following procedure is recommended for this purpose:

The propeller blades should be assembled in the hub at the proper angle and pulled out firmly against the shoulders before clamping the ring. The ring should then be drawn fairly tight at the position indicated by the arrows. The propeller should then be placed on the balancing stand and the balance observed with the blades in a vertical position. If the propeller is found to be out of balance, the clamping rings may be loosened and rotated about the hub so that the bolt will move toward the light side of the propeller. In this way perfect vertical balance may be secured.

ETCHING ALUMINUM ALLOY PROPELLER BLADES

The purpose of etching is to clean the surface of the metal, and show up any cracks which may have started as a result of continual use. This inspection should be done at the factory or at authorized service stations. It is a standard practice of the Army and Navy to etch and examine aluminum alloy propellers after every 100 hours of service. The blades are swabbed with, or preferably immersed in, a 10 to 20 per cent solution of commercial caustic soda of the same temperature as the propeller for from two to six minutes. They are then rinsed in water and swabbed with or immersed in a 5 per cent solution of nitric acid until bright, after which they are thoroughly washed with water and dried. The surface is carefully inspected for cracks, preferably with a low-power magnifying glass. If any cracks or flaws are found, the surface is sanded off a little and given a deeper local etch. Small longitudinal seams which are rolled or forged into the material are not important, but cracks across the blade which penetrate under the surface are usually a sign of impending fatigue failure and are cause for rejection. In commercial service it is considered satisfactory practice to etch and examine the blades every few hundred hours

VIBRATION

The question of vibration in the power plant, propeller, and mounting is a very important one. There are, of course, a number of possible causes of vibration. One of the most obvious causes is the static unbalance of the propeller, which can be controlled by inspection. The dynamic unbalance of the propeller can be controlled within fairly close limits by checking the face alignment or track of the blades at a number of stations.

An aerodynamic unbalance of the propeller may be caused, as is well known, by unequal angle setting of the two blades. It may also be caused by improper template fit of the two blades, resulting in different characteristics for the airfoil, and this feature is carefully controlled by inspection at the factory.

An unequal amount of stiffness in the two blades of the propeller may also cause vibration, as the blades will deflect by unequal amounts. In Hamilton Standard Propellers, this condition is not found, as the material is carefully tested to insure uniformity of structure and hardness.

There are, of course, possibilities of vibration coming from the engine, even assuming good distribution, ignition, and timing. One

of these is the uneven torque reaction due to the gas pressure. A second source of vibration comes from improper balance of the reciprocating parts.

However, vibration frequently occurs at certain speeds, and is comparatively small in amount at other speeds. This is often the result of the period of vibration of some of the parts coinciding with the rate of engine impulses or with the rate of revolution. It can sometimes be eliminated by changes in the mounting of the engine or by changes in propeller design.

CHAPTER XV

GLOSSARY OF AIRCRAFT ENGINE TERMS

In the following explanations self-explanatory words have been omitted unless they have been subjected to misuse or convey erroneous impressions. Ordinary dictionary words have likewise been considered redundant in many cases, as have names of parts favored by individual manufacturers.

Accelerator Pump.—A small piston actuating in a cup or cylinder of gasoline attached to some carburetors and arranged with the throttle to provide a rich mixture to engine when engine is accelerated.

Admission.—Sometimes referred to the intake of gas into the cylinder of an internal combustion engine, as *admission stroke.*

Advance.—To move forward, ahead, earlier. (1) Advance of the spark for ignition is accomplished by moving the breaker mechanism against the rotation of cam actuating the breaker contact points or by advancing the position of the cam. (2) Sometimes refers to the opening of the throttle.

Advanced Spark.—The condition of timing the spark to occur in the combustion chamber at the earliest possible time before firing top center. That position of the spark lever which provides the earliest possible ignition. *See* Advance.

After-firing.—The explosion of gas in the exhaust pipe. Erroneously called back-firing. *See* Back-firing.

Air-bound.—An air pocket in radiator or water line caused by filling cooling system without permitting air in pipes to escape during filling operation.

Air-cooled.—Generally used in referring to engines which are cooled by air directly upon the cylinders, to distinguish from engines having water jackets about the cylinders to absorb the heat.

Air Gap.—A space provided in the secondary circuit of an ignition system to permit high-tension current to jump. Also known as an Auxiliary Gap. *See* Spark Intensifier.

Alternating Current.—An electric current which rapidly reverses its flow periodically. The flow reverses at such frequent intervals that there is no set positive or negative flow. Alternating current pressure is produced by electromagnetic induction machines having slip rings or collector rings to collect the current from the armature. A magneto is an example of an alternating current generator and is equipped with a collector ring if the magneto is of the armature type. A dynamo or commonly called generator used for starting and lighting is equipped with a commutator which rectifies the alternating current set up in the armature, to a direct current.

Altitude Valve.—A manually controlled valve to bring about a leaning down of

the carburetor mixture when very high altitudes are reached with an aeronautical engine.

Ampere.—The unit of measure of the rate of flow of an electric current. The current flowing through a circuit having a resistance of one ohm under a pressure of one volt.

Ampere Hour.—The quantity of electricity delivered in one hour by a current averaging one ampere. One ampere flowing for one hour is one ampere hour. Two amperes flowing for one hour is two ampere hours, etc.

Ampere Turn.—A current of one ampere flowing through a coil of one turn. Used to express the strength of a magnetic field around a coiled conductor. A coil of ten turns with five amperes flowing has a magnetic field strength of fifty ampere turns.

Annular Ball Bearing.—Meaning ring-shaped. A bearing with an inner and outer race. Not adjustable and not capable of taking a thrust load.

Anti-clockwise.—Also known as *counter-clockwise*. The direction of a shaft, gear, or wheel turning to the left from its driven end. A movement opposite to the direction which the hands of a clock turn.

Anti-friction.—(1) Any bearing made of composition to reduce friction. (2) A bearing offering a minimum amount of friction, as a ball bearing.

Anti-normal Engine.—*See* Left-hand Engine.

Anti-propeller End.—The end of the engine crankshaft opposite the propeller end of shaft.

Armature.—(1) That part of any electrical apparatus which serves to close or complete the magnetic circuit. (2) That part of a motor, generator, or magneto made of soft iron, carrying inductors, and revolving in the magnetic field. (3) A piece of magnetic material placed across the legs of a magnet to close the magnetic circuit. *See* Keeper.

Armature Core.—That part of the armature made of solid soft iron or stampings of soft iron. *See* Armature.

Armature Head.—That part of the armature assembly made of brass or other non-magnetic material which connects armature shaft with armature core.

Armature Lag.—A certain amount of time is required to change the rate of magnetic flux through armature core. The electric current lags slightly behind the electromotive force that is set up in the armature winding, because of self-induction.

Armature Type.—That type of generator or magneto having a stationary field and revolving coils, to distinguish from **inductor** type in which the coils are stationary and the magnetic field is revolved.

Armature Winding.—The inductors (insulated wire) wound upon the armature core. The windings or coils in slots of armature.

Articulated Rods.—*See* Link Rods.

Artificial Magnets.—Any magnet which is or has been charged, to distinguish from earth's natural magnet, loadstone.

Atomize.—To break up into minute particles or atoms.

Auxiliary Gap.—*See* Spark Intensifier.

Back-firing.—An explosion which occurs through the inlet manifold and carburetor, caused by an internal-combustion engine attempting to run backward when started with too early timed ignition, the inlet valve momentarily becoming the exhaust valve. The term is erroneously used in referring to explosions through carburetor when engine is running in correct direction. *See* Popping Back. A

back-fire is accompanied by a *back-kick* if the explosion is of sufficient strength to drive piston back before it reaches firing top center. The term is also erroneously used in referring to explosions in the exhaust pipe. *See* After-firing.

Back-kick.—A violent reversal of an internal-combustion engine due to complete combustion occurring before piston has reached firing top center. A *back-kick* may occur either when starting an engine by hand or with a starter if the ignition is advanced when starting. A *back-kick* is usually accompanied by a *back-fire*. *See* Back-firing.

Back Pressure.—Term used in referring to restricted exhaust discharge into an undersized exhaust pipe, or to the pressure tending to retard movement of piston on the exhaust stroke caused by improperly timed exhaust valve making an excessive pressure within cylinder at bottom center.

Ballast Resistor.—*See* Resistance Unit.

Ball Cage.—A metal cage for holding balls in a ball bearing at evenly spaced positions.

Ball Check.—A check valve having a ball resting against a seat which permits any pressure to pass but one way. Used in air pumps and oil pumps to prevent back-up of pressure into pump.

Ball Float.—A ball-shaped carburetor float resting upon a metal strip to control fuel needle valve.

Bank.—Bank of cylinders refers to a row of cylinders cast singly in a V-type engine, as left or right bank to distinguish from left or right block where cylinders are cast together, better known as *in-block.*

Barrel-type Crankcase.—An engine crankcase so constructed that crankshaft must be removed from one end of case. Term used to distinguish from the **split-type** crankcase.

Block.—A casting of two or more engine cylinders together.

Blow Back.—Blowing of the intaked gas back through the carburetor at low engine speed caused by inlet valve closing too late in compression stroke. Sometimes used in referring to *popping back* through the carburetor.

Blow By.—The blowing by or leaking of compression past piston and piston rings during compression stroke, or the leaking of combustion past the piston and rings during the power stroke.

Booster Magneto.—A starting magneto supplying a high-tension current for ignition. The booster magneto is either cranked by hand or driven by starter through an automatic connection, and supplies a shower of sparks for ignition when the regular magneto is not being driven fast enough to provide a hot spark.

Bore.—The hole made by boring, as the inside diameter of an engine's cylinder.

Boss.—A protuberant part, like piston bosses; the heavy reinforcements inside piston in which piston pin turns or is held.

Bottom Center.—The position of the piston in an engine when at the lower end of a stroke. The outer or lower dead position of the crank.

Brake Horsepower.—The power actually delivered by the engine crankshaft.

Breaker.—Term used in referring to ignition contact breaker or circuit interrupter.

Breaker Cam.—The cam actuating the ignition breaker contacts.

Breaker Contacts.—The platinum or tungsten steel points of an ignition circuit interrupter.

Breather Pipe.—A vent pipe into the crankcase of an engine to allow crankcase pressure and heat to be released.

British Thermal Unit (B. T. U.).—The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at its maximum density, which is 39.1° F. One pound of gasoline averages from 19,000 to 20,000 B. T. U.

Brush.—A carbon block or pencil, or a copper wire gauze block used to make a wiping contact upon a commutator or collector ring of a generator or magneto, etc.

Brush Type.—Refers to an ignition distributor in which a brush of carbon or metal is employed to make a wiping contact, to distinguish from the *gap type.*

Burnt-out Bearings.—Any plain bushing of babbitt metal or bronze burnt or destroyed by heat and friction from being too tight or improperly lubricated.

Burnt-out Coil.—Any coil of electric conductor which has been subjected to an excessive current resulting in either melting of the conductor or burning of the insulation.

Bushing.—A detachable lining of a bearing, as a plain metal sleeve made of antifriction metal, usually bronze or babbitt metal.

Butterfly Valve.—A disc turning on a diametral axis inside a pipe. A turning pin with wings to close a passageway in a pipe; a damper. Used extensively in carburetors for a throttle valve and in the air opening as a choke.

Calorific Value.—The value in British thermal units of various hydrocarbon fuels such as gasoline, kerosene, etc. *See* British Thermal Unit.

Cam.—An eccentric projection on a revolving shaft designed to give a variable motion to an object, as the projections on the camshaft of an engine which raise the valves from their seats.

Cam Contour.—The outline or shape of a cam which determines the amount of lift given to the valve and the speed with which the valve is opened and permitted to close for a given engine speed.

Cam Follower.—That part of a valve lifting mechanism in contact with the cam. The follower may be a roller or of the mushroom type.

Camshaft.—A steel drop-forging with eccentric projections (cams) which revolves, operating the valves of an internal-combustion engine. Cams of the camshaft are carefully ground for accuracy and hardened to prevent wear. Camshaft turns at one-half the speed of the crankshaft in order to open and close the valves at the proper time.

Canting of Piston.—Refers to movement of piston at an angle to cylinder wall by thrust because of varying angularity of connecting rod.

Capacity.—(1) An electrical storage battery has capacity for holding a charge, measured in ampere hours. (2) A conductor has a certain capacity for carrying an electric current. (3) A condenser has a capacity for holding a static charge.

Cap Jet.—A gasoline spray nozzle with a large mouth, the flow of gasoline being regulated by a smaller opening than the mouth located lower in the carburetor.

Carbon.—(1) An elementary substance found in minerals and all organic substances. (2) A constituent of gasoline. (3) The deposit left in the combustion chamber of an internal-combustion engine.

Carbon Dioxide.—A heavy, colorless, odorless gas. An anti-combustion gas which if not exhausted from an engine destroys the combustibility of the succeeding fresh charge.

Carbon Knock.—An engine knock resulting from incandescent carbon in the combustion chamber igniting the gas prematurely.

Carbon Monoxide.—A poisonous gas resulting from incomplete combustion of carbon.

Carbon Residue.—Refers to carbon deposit in combustion chamber of an engine after combustion of hydrocarbons.

Carburetor.—An apparatus that mixes hydrocarbon fuels with air, or carburizes air, thus forming a combustible gas.

Carburetor Air-Heater.—A metal sleeve or funnel-shape piping around or near exhaust pipe to collect warm air for the air intake of a carburetor. Also known as *Hot Air Stove.*

Cardan Joint.—French term for universal joint. Frequently used.

Cast-in-Block.—Any number of cylinders of an engine cast in a single casting. To distinguish from cast-singly or cast-in-pairs. Also known as *monobloc.*

Center.—Refers to the position of piston or crank throw of crankshaft when piston is at a standstill momentarily at the beginning or ending of any stroke. *See* Top Center, Bottom Center, and Dead Center.

Centrifugal Pump.—A water pump having blades that revolve in a casing and propel water through the cooling system of an internal-combustion engine.

Charging Cylinders.—Refer to rotating an engine with ignition switch off while carburetor is being choked to obtain a rich mixture so that the cylinders will be filled with a rich mixture to facilitate starting.

Charging Stroke.—Sometimes used in referring to the intake stroke of an internal-combustion engine.

Choke.—Refers either to a venturi tube in a carburetor or the butterfly valve in the air intake.

Choking.—The act of closing the air intake passageway in a carburetor to obtain a rich starting mixture.

Circuit.—The complete path of an electric current.

Clearance.—(1) The gap between a valve stem and the valve tappet. (2) The space between a piston and the cylinder wall to allow for the expansion of the piston when heated. (3) The space between the piston and the cylinder head when piston is at top center.

Clockwise.—Like the motion of the hands of a clock. Term used to indicate the direction a gear or shaft turns, as, *clockwise magneto*, indicating that the magneto turns to the right when facing its driven end. *See* Anti-clockwise.

Closed Circuit Ignition. That ignition system which employs a breaker cam actuating the breaker contact points which permits the breaker points to be normally closed; the points opening the instant ignition is desired. To distinguish from Open Circuit Ignition.

Closed Magnetic Circuit.—A magnetic circuit which is completed through magnetic material, for instance, the soft iron core of an armature being close to the poles of the field completes the magnetic circuit.

Collector Ring.—(1) Also known as *slip ring.* A continuous metal surface on a revolving armature of a magneto against which a brush bears, collecting the generated current. (2) A circular exhaust pipe fitted to some radial engines.

Combustion Chamber.—The space at the closed end of the cylinder of an internal-combustion engine. Particularly the space between piston and cylinder head when piston is at its uppermost position.

Combustion Knock.—An engine knock caused by detonation of gas due to variations of compressed fuel. Also called *gas-knock.*

Combustion Stroke.—The power stroke, impulse stroke, working stroke, or firing stroke of an internal-combustion engine.

Compensating Type Carburetor.—A type of carburetor which provides a uniform mixture by automatically counteracting variations.

Compensating Well.—A small gasoline reservoir in some carburetors in which gasoline is stored to be used when necessary to counteract excessive air.

Compensation.—The principle or act of compensating, as a means of counteracting variations in a carburetor. *See* description in text under Carburetion.

Compensator.—A jet in some carburetors which decreases the flow of gasoline as suction increases.

Compound Nozzle.—A combination of two or more spray nozzles in a carburetor, usually but two, one nozzle counteracting the defects of the other.

Compression.—(1) In an internal-combustion engine, compression refers to the squeezing, condensing, or compressing of the combustible mixture between the piston head and the cylinder head. (2) Compression is a strain produced in a piece of metal when there is a tendency to shorten same, as the compression strain in a connecting rod when subjected to pressure during the firing stroke of an engine.

Compression Dead Center.—The uppermost position of the piston at the end of the compression stroke. Firing top center.

Compression Ring.—An iron ring having an opening and fitted into a groove in the piston. Compression rings are provided to make the piston gas tight in the cylinder by expanding against the cylinder wall.

Compression Space.—The varying clearance between the piston head and the cylinder head; refers particularly to this space when the piston is in its uppermost position.

Concave Piston.—A piston having a head with a low center for the purpose of reducing cylinder wall exposure to combustion without reducing the size of the combustion chamber.

Concentric Float Chamber.—A carburetor having the float chamber around the mixing chamber, both having a common center. *See* Eccentric Float Chamber.

Concentric Piston Ring.—A compression ring having the same thickness at all points. *See* Eccentric Piston Ring.

Condenser.—A device capable of condensing and holding a charge of electricity. Used in all ignition systems. Shunted across the breaker contact points, the condenser absorbs the excess current from the primary winding of the induction coil when points open and prevents burning of the points, and likewise assists induction of a high pressure in the secondary winding by bringing about a rapid demagnetization of the iron core.

Conductor.—Any substance which transmits an electric current or heat.

Connecting Rod.—Usually a steel drop-forging I-beam section which connects the piston to the crankpin. The small end of the connecting rod holds the piston by means of the piston pin, the large end having a bushing upon the crankpin of the crankshaft.

Contact Breaker.—Breaker contact points which open an electric circuit, particularly the primary circuit of an ignition system.

Contact Sector.—The metal contact or segment in an ignition distributor.

Convex Pistons.—A piston having a rounded head, dome-shaped.

Counterbalance.—A weight that balances another weight. Refers to weights attached to some crankshafts opposite the crank-throws to balance the weight of the crank-throw and thereby reduce vibration.

Counter-clockwise.—Same as Anti-clockwise.

Countershaft.—An intermediate shaft for receiving and transmitting motion through a train of gears.

Counterweight.—*See* Counterbalance.

Crank.—(1) An arm at right angles to a shaft to impart motion or to receive motion, as the crank-throw of a crankshaft which receives motion from the piston on the power stroke and imparts a rotary motion to the crankshaft. (2) The starting crank for revolving the crankshaft by hand.

Crank Angle.—Used in referring to the angle in degrees any particular crank-throw of a crankshaft has traveled after or before a dead center.

Crankcase.—That part of the engine which supports the crankshaft, timing gears, camshaft, oil pan, and cylinders.

Crankcase Dilution.—Refers to the thinning and contaminating of the crankcase oil with the heavy ends of gasoline which reaches the crankcase past the pistons.

Crank Center.—The same as *bottom center* or *lower center*. The center nearest the crank.

"Cranking with Starter."—An expression used in referring to the revolving of an engine crankshaft by the use of the starting motor.

Crankpin.—The journal of a crank-throw of a crankshaft to which the connecting rod is attached.

Crankshaft.—A shaft which is rotated by offset cranks.

Crank-throw.—The crank or off-set part of a crankshaft.

Critical Scavenging Point.—Top center at the finish of the exhaust stroke where the last opportunity is provided to rid the cylinder of burnt gases.

Critical Speed.—That speed of an engine which is the turning-point of vibrations.

Crystallize.—The weakening of a metal through crystallization, believed to be caused sometimes by vibration or age.

Cycle.—(1) In an alternating current one complete set of positive and negative values. (2) In an internal-combustion engine, a complete course of events or the series of operations. *See* Four-stroke Cycle and Two-stroke Cycle.

Cylinder Head.—The top of the cylinder, sometimes removable, and in valve-in-head engines, containing the valves.

Damper.—*See* Butterfly Valve.

D. C.—An abbreviation for *dead center*. An abbreviation for *direct current*.

Dead Center.—The position at either end of a stroke when a crank of the crankshaft and the connecting rod are in the same straight line.

Dead Short Circuit.—A short circuit that offers so little (or no) resistance that the entire current finds a return.

Deflector.—A deflector in a two-stroke cycle engine consists of a raised section of the piston head to prevent the intake gas from being drawn out with the exhaust at the end of the power stroke and up to the time the exhaust port is closed.

Degree.—One three-hundred-and-sixtieth part of the circumference of a circle.

Demagnetize.—To deprive of magnetic properties.

Detachable Head.—Refers to a removable cylinder head of an engine.

Diameter of Cylinder.—The inside diameter of the cylinder bore.

Direct Current.—A practically non-pulsating current flowing in one direction.

Distant Thermometer.—A thermometer provided with a long tube to permit the sensitive element to be at a distance from the indicator dial. Also known as an *Extension Thermometer*.

Distributor.—That part of an ignition system which distributes the high-tension current to the spark plugs in the proper sequence.

Distributor Cap.—The insulated head of an ignition distributor containing the contacts or segments which distribute the secondary current supplied through the revolving rotor.

Distributor Rotor.—The revolving member of an ignition distributor which carries a brush in contact with the segments of the distributor. In some cases the rotor is not fitted with a brush, the current leaping a short gap between the rotor and the segments.

Dog.—Any device for fastening, holding, or gripping something so as to obtain a positive connection.

Dome Piston.—*See* Convex Piston.

Double Ignition.—Two separate ignition systems, each provided with a set of spark plugs.

Double Opposed Engine.—A two-cylinder engine with cylinders opposite one another and cranks of the crankshaft set 180 degrees apart.

Double Venturi.—The employment of two venturi tubes in a carburetor to further increase the air velocity.

Dowel Pin.—A pin fitting into a hole of two joined objects to prevent slipping, or between two parts where perfect alignment is necessary.

Dry Sump.—That system of engine lubrication in which the upper crankcase is kept dry by scavenger pumps, lubrication of crankshaft bearings being accomplished by force feed through hollow crankshaft.

Dual Valves.—Refers to the employment of two inlet valves and two exhaust valves to each cylinder of an engine, in order to increase the size of the port area without a large single valve which would have to be heavy to prevent warping, and this in turn would make necessary heavy springs to insure closing the heavy valve.

Dummy Journal.—A machine-finished section of a crankshaft resembling a journal.

Duplex Carburetor.—A carburetor having two separate mixing chambers fed by a single float chamber. Used on some V-type engines.

Dynamometer Test.—The testing of an engine by connecting with a dynamo and calculating the power of the engine by measuring the electrical energy generated by the dynamo.

E. C.—An abbreviation for *exhaust closed.*

Eccentric Float Chamber.—A carburetor float chamber offset from the mixing chamber, the float chamber and the mixing chamber having different centers. *See* Concentric Float Chamber.

Eccentric Piston Ring.—A piston ring thicker at the point opposite the opening in the ring. *See* Concentric Piston Ring.

Eduction Stroke.—Refers to the exhaust stroke of an internal-combustion engine.

Ejection Stroke.—Refers to the exhaust stroke of an internal-combustion engine.

Electrical Lag.—Refers to a slight lagging of an electric current, particularly to the spark at the spark plug in relation to the speed of the piston.

Electromagnet.—A soft iron core wrapped with a conductor. A current passing through coiled conductor magnetizes the core by induction only during the time current is passing through coils.

E.M.F.—An abbreviation for *electromotive force*, meaning the electrical pressure, potential or voltage.

En-bloc.—*See* Cast-in-block.

E.O.—An abbreviation for *exhaust open.*

E.P.M.—An abbreviation for *explosions per minute.*

Ether.—A highly volatile, inflammable fluid used for priming a cold engine to facilitate starting. Its use is not recommended.

Evaporation.—The act of passing off into a vapor. The carburetor evaporates the liquid fuel, forming a dry gas if sufficient heat is supplied.

Event.—*See* Four-stroke Cycle.

EX.C.—An abbreviation for *exhaust closed.*

Excite.—To create a magnetic field by induction.

EX.CL.—An abbreviation for *exhaust closed.*

EX.OP.—An abbreviation for *exhaust open.*

Exhaust Period.—The duration of the exhaust event. The number of degrees the exhaust valve is open.

Expanding Type Carburetor.—A carburetor having a number of set jets which are uncovered one after the other as a rotary throttle is opened.

Expansion.—The spreading out or increasing in volume. Expansion of the gases in an internal-combustion engine results from the heat of combustion, and the expansion pressure upon the movable piston head creates power.

Explosion.—Very rapid combustion accompanied by violent expansion.

Extension Thermometer.—*See* Distance Thermometer.

External Circuits.—The wiring between electrical units. The circuits of a starting and lighting or ignition system outside the motor, generator, magneto, or coil. To distinguish from the internal circuits of these units.

Face of Valve.—That part of a valve which is beveled and fits valve seat, or any part of a valve to fit the valve seat.

Firing Order.—The order in which the cylinders of a multi-cylinder engine fire.

Firing Stroke.—The power stroke of an internal-combustion engine. The working stroke.

Firing Top Center.—The position of the piston when in its uppermost position at the end of the compression stroke.

Fixed Spark.—Also known as *set spark*. *See* description in text under Ignition Timing.

Float Bowl.—The float chamber of a carburetor. The chamber that holds the float and a supply of gasoline for the spray nozzle.

Float.—A buoyant metal or cork float used in carburetors to operate a needle valve and maintain a constant level of gasoline in chamber and spray nozzle.

Float Chamber.—*See* Float Bowl.

Float Counterbalance.—Small weights held by arms from a collar attached to needle valve in the float chamber of a carburetor. The weights balance the float and the needle.

Floating Wrist Pin.—A wrist pin (piston pin) which has a free fit in both the connecting rod and the piston bosses.

Flooding Carburetor.—Refers either to a carburetor which is overflowing the spray nozzle and float chamber, or to the intentional sinking of the float in order to obtain a rich mixture.

Forced Circulation.—The circulation of water through the cooling system of an

internal-combustion engine by means of a pump. To distinguish from thermosyphon system of circulation.

Force Feed.—Lubrication of an engine by forcing oil to main bearings and connecting rods through hollow crankshaft. *See* Full Force Feed.

Forked Connecting Rod.—The large end of a connecting rod fork-shaped to permit another connecting rod to be fitted between gap in fork. Used in V-type engines to enable engine blocks to be parallel.

Four Cycle.—*See* Four-stroke Cycle.

Four-stroke Cycle.—The series of events taking place in an internal-combustion engine during the four strokes. Intake, compression, power, and exhaust comprise the complete cycle accomplished in the four strokes or two revolutions.

F.P.M.—An abbreviation for *feet per minute.* Refers to the number of feet traveled by a piston in one minute.

"Frozen Bearing."—An expression used in referring to a seized bearing from running without proper lubrication.

Frozen Carburetor.—May refer to ice in the float chamber or from a frozen water jacket about the mixing chamber.

"Frozen Engine."—An expression used in referring to the seizing of pistons to cylinder walls or seizing of engine bearings or both, due to running engine without proper lubrication or from parts being fitted too tight. Also refers to the water in the water jackets of the cylinders being frozen from low temperature.

Full Force Feed.—Refers to an engine lubrication system in which oil is forced to all crankshaft bearings and up a tube attached to the connecting rod to provide positive lubrication of the wrist pin and cylinder walls.

"Galloping."—An expression used in referring to an irregular running of an internal-combustion engine due to a rich mixture.

Gap Type Distributor.—An ignition distributor which has the rotor passing near but not in actual contact with the segments, the spark leaping the short gap to complete the secondary circuit. To distinguish from the brush-type distributor.

Gas Engine.—Popularly refers to any type of an internal-combustion engine whether a dry gas or a wet mixture is employed.

Gas Knock.—*See* Combustion Knock.

Gassing.—The bubbling of the electrolyte in a storage battery cell due to liberated gas toward the end of the charge.

Gear Pump.—An oil pump in which the teeth of gears are used to obtain a pumping action.

Gear Train.—A series of meshed gears for obtaining various shaft speeds or reverse motion.

Good Compression.—Refers to the correct compression intended for an engine whether high or low.

Gravity Fuel System.—The simple system of supplying the liquid fuel to the carburetor by placing the supply tank above the level of the carburetor float chamber.

Grinding Cylinders.—A method of reclaiming "out of round" or scored cylinders by use of a grinding machine. A high-speed wheel made of abrasive material moving in a circular path grinds the cylinders the desired oversize.

Grinding Valves.—A process of seating the face of a valve to the valve seat by the use of an abrasive between the valve face and the valve seat.

Ground.—A term used in referring to the metal framework of an airplane, or the use of the metal of an engine in place of a return wire for any electrical circuit.

The term originated from using the ground (earth) as a return for telegraph, telephone, and other electrical circuits.

Ground Returns.—*See* Ground.

Ground Wire.—A conductor that connects any unit of an electrical system with the metal framework. *See* Ground.

Gudgeon Pin.—Same as *piston pin* or *wrist pin.*

Half Speed Shaft.—The camshaft of an internal-combustion engine.

Head Center.—Same as *top center.*

Head of Piston.—The upper part of the piston, to distinguish from the *skirt* of the piston.

Heat Units.—*See* British Thermal Unit.

High Compression Ring.—A piston ring designed to reduce leakage of compression to a minimum.

High Tension.—An electrical term used in referring to an electric current of high voltage. High potential.

High-tension Coil.—*See* Induction Coil.

Homogeneous Mixture.—Refers to the mixing of liquid fuel with air in proportions that result in an intimate compound.

Hot Air Horn.—An elbow resembling a horn to connect the air intake of a carburetor with the air heater.

Hot Air Stove.—*See* Carburetor Air Heater.

Hot Spot Manifold.—A combining of the exhaust and inlet manifolds in a single casting in such a manner that a portion of the inlet passageway is heated.

Hourglass Piston.—A light piston having a small area of contact with the cylinder owing to its shape which resembles an hourglass.

H.P.—An abbreviation for *horsepower.*

Hydrocarbon.—A compound of hydrogen and carbon, as gasoline, kerosene, benzine, etc.

Hydrocarbon Engine.—Any internal-combustion engine using a hydrocarbon fuel.

I.C.—An abbreviation for *intake closed.*

Idler Gear.—Any gear placed between two others to transfer motion without changing the direction of rotation or ratio.

Idling Adjustment.—A carburetor adjustment for low engine speed when engine is not under a load (idling).

Idling Stop Screw.—An adjustment for regulating the amount of throttle opening in a carburetor when throttle is near the closed position. Used to prevent the throttle from closing entirely when throttle lever is in the closed position.

I Head.—That type of engine having both the exhaust valve and the inlet valve in the cylinder head. Same as *valve-in-head* or *overhead valves.*

Impulse Stroke.—The power stroke of an internal-combustion engine.

IN.C.—An abbreviation for *inlet closed.*

IN.CL.—An abbreviation for *inlet closed.*

Indicated Horsepower (I.H.P.).—The power delivered to the piston as measured by an indicator giving the pressure of the explosion. The horsepower an engine would deliver if no power were consumed by the engine in driving itself.

Induction Coil.—The ignition coil, transformer coil, or step-up coil by which the low voltage of the battery is transformed to a very high voltage.

Induction Stroke.—The suction or inlet stroke of an internal-combustion engine.

Inductors.—Insulated wires placed upon the armature of a generator or magneto which when moved or rotated in a magnetic field have an electrical pressure induced in them.

Inlet Manifold.—*See* Manifold.

Inlet Period.—The duration of the inlet or intake event. The number of degrees the inlet valve is open.

Inlet Port.—The opening uncovered by the inlet valve when open.

Inlet Stroke.—The downward movement of the piston of an internal-combustion engine when the inlet valve is open. The induction stroke, the charging stroke, the intake stroke, the suction or admission stroke.

IN.O.—An abbreviation for *inlet open.*

IN. OP.—An abbreviation for *inlet open.*

Insulating Base.—Usually refers to the non-magnetic base of a magneto.

Internal Circuit.—The electrical circuits within a magneto, coil, generator, starting motor, etc. To distinguish from the external circuits in which the units are connected.

Internal Combustion.—Pertains to any engine that develops the necessary pressure energy by burning of fuel within the cylinder.

Interrupter.—Any device that interrupts or breaks an electrical circuit. Same as *contact breaker* or *circuit interrupter.*

Inverted Engine.—A type of engine in which the cylinders are below the crankshaft.

Inverted V-Type Engine.—*See* Inverted Engine.

I.O.—An abbreviation for *inlet open.*

Jacket.—Any outer covering or casing, as the water jacket about the cylinder of an engine, the hot-water jacket about a carburetor mixing chamber, or the hot-water jacket about some inlet manifolds.

Jet.—A nozzle, as a spray nozzle for a carburetor.

Journal.—That portion of a rotating shaft which turns in a bearing.

Jump Spark.—Term sometimes used in referring to ignition which employs a high-voltage current capable of jumping an air gap.

Keeper.—A piece of magnetic material, usually iron, placed across the poles of a permanent magnet to close the magnetic circuit.

"Kick-back." *See* Back-kick.

Lag.—Refers particularly to that which is retarded (late). *See* Valve Lag.

Laminated Core.—A group of soft iron stampings used instead of a solid core for an armature of a magneto, generator, or motor. Prevents the circulation of eddy currents set up in the core from induction.

Lean Mixture.—Refers to a proportion of gasoline and air in which air is either in excess of the desired amount or purposely near the limit.

Left-hand Crankshaft.—A crankshaft having three pairs of crank-throws 120 degrees apart in which the throws 3 and 4 are on the left when 1 and 6 are vertical and viewed from the forward end of the shaft. *See* description in text under Firing Orders.

Left-hand Engine.—An anti-normal engine. An engine in which the propeller shaft turns counter-clockwise when viewed from the anti-propeller end of the engine.

L Head.—That type of engine having both the exhaust valve and the inlet valve in a pocket on one side of the cylinder. Resembles an inverted L.

Link Rods.—The connecting rods of a radial engine which are attached to the master rod by means of knuckle pins.

"Loading Up."—An expression used in referring to the condensation of gasoline in the inlet manifold because of insufficient heat or improper carburetor adjustment providing a rich mixture. The accumulation of gasoline in the inlet manifold causes the engine to run irregularly after running idle at low speeds.

Lobe.—A rounded projection or cam. Usually refers to the projections on an ignition timer-distributor shaft for operating the breaker contact points.

Long Stroke.—The stroke of an internal-combustion engine in which the ratio of the stroke to the bore is greater than 1.5 to 1.

"Lopping."—An expression used in referring to an irregular running of an engine.

Low Compression.—A compression from 45 to 60 lb. Not to be confused with poor compression, for an engine designed for 60 lb. compression will have good compression at 60 lb. yet be a great deal weaker than an engine designed for 80 or 100 lb. compression.

Lower Center.—Same as *bottom center* or *crank center.*

Lower Crankcase.—Term used to describe the lower part of an engine crankcase when the lower half contains bearings.

Magnet.—A mass of iron or steel producing a magnetic field.

Magnetic Circuit.—The path of magnetic lines of force passing from the north pole of a magnet to the south pole externally, and from the south pole to the north pole internally.

Magnetic Field.—The region about a magnet and particularly the space between the poles of a magnet within which there are lines of force.

Magnetism.—The property of a body for producing attraction or repulsion between two pieces of iron.

Magneto.—A magneto-electric machine employing permanent magnets for the field. Used for ignition in internal-combustion engine.

Magneto Breaker Box.—The enclosed breaker contact assembly.

Magneto Distributor.—The insulated block carrying segments for distribution of the secondary current.

Main Bearing.—Any principal bearing of great strength, for instance, the bearings supporting the crankshaft of an internal-combustion engine.

Manifold.—A pipe fitting or casting with several outlets. Used between carburetor and cylinders of an internal-combustion engine or to carry off the exhaust heat and gases.

Manual Control.—To operate any control by hand. To distinguish from automatic control.

Master Rod.—The main rod of a radial engine to which the link rods are attached.

Mechanical Lag.—Usually refers to the tardiness of a spark for ignition because of the piston traveling at high speeds and the spark taking place a trifle late owing to time factor for mechanical parts of the ignition system to operate. Mechanical lag is one factor which makes the advancing of the spark necessary.

"Miss."—*See* Misfire.

Misfire.—Failure to fire, as the failure of the gas to ignite in a cylinder of an internal-combustion engine.

Miter-cut Ring.—A piston ring which has a beveled cut opening.

Monobloc.—The casting of all the cylinders of an engine in a single casting.

Mother Rod.—*See* Master Rod.

Motor.—A prime mover, as a steam engine, internal-combustion engine of compact construction, or an electric motor. To distinguish from the internal-combustion engine the name should be confined to the electric motor to avoid confusion.

Mushroom Valve Plunger.—A cam follower having the form of a mushroom. To distinguish from the roller type cam follower.

Needle Valve.—A slender pin or rod pointed at one end and resting upon a seat to prevent the passing of a liquid, or to control the passage of a liquid. Used in some spray nozzles of carburetors and in the float chamber of most carburetors.

Negative.—(1) Opposed to positive. (2) Negative electricity is the opposite charge to positive electricity. (3) That terminal of a generator of electrical pressure through which the current is said to return to complete a circuit, as the negative terminal of a storage battery or generator, sometimes indicated by a minus mark (−).

Neutral Point.—That point in valve timing at the instant a cycle is completed in a cylinder and a new cycle of events commences. That point where the exhaust valve closes and the inlet valve starts to open.

Non-conductor.—Any substance or body that is a very poor conductor of electricity, heat, or sound, etc. The term is usually associated with substances which are insulators against the flow of an electric current.

Non-inductive Winding.—A coiled conductor with the same number of turns in either direction in order to neutralize its magnetic field.

Non-vibrating Coil.—An induction coil or transformer coil for ignition purposes not equipped with a vibrator for interrupting the primary circuit. That type of transformer coil which gives a single spark at the spark plug instead of a shower of sparks as given by vibrating coils.

North Pole.—(1) That pole of a magnet from which the magnetic lines of force flow. (2) That end of a compass needle pointing in approximately the direction of the north geographical pole. The north-seeking pole of a compass. That pole which has an attraction for the south pole of a magnet. (3) The magnetic pole near the south geographical pole.

Normal Engine.—*See* Right-hand Engine.

Nose of Cam.—The offset or eccentric part of a cam.

Nozzle.—Any projecting spout or tube, usually tapering, for instance, the fuel spray nozzle of a carburetor.

Offset Cylinders.—The arrangement of the cylinders so that the center line through the cylinders is offset from the center line of the crankshaft.

Ohm.—The unit of electrical resistance.

Ohm's Law.—The definite relation existing between the strength of an electric current, resistance, and the potential. The voltage is equal to the current multiplied by the resistance. The resistance is equal to the voltage divided by the current in amperes. The current is equal to the voltage divided by the resistance.

Oil Fed with Fuel.—Refers to the mixing of a small quantity of lubricating oil with the gasoline to insure lubrication of the piston and cylinder walls while "running in" a new engine.

Oil Gage.—Any gage indicating the quantity of oil in a reservoir or to indicate the pressure upon the oil.

Oil Level.—The height of the lubricating oil in an engine, as high level or low level.

Oil Pan.—A metal pan beneath engine crankcase used for the lower part of engine case and usually as the oil reservoir.

Oil Pressure Relief Valve.—A valve so arranged as to relieve the pressure upon an oiling system when pressure becomes too high.

Oil Ring.—A piston ring to prevent an excessive amount of oil from reaching the combustion chamber.

Open Circuit.—Refers to the breaking of an electrical circuit, either intentionally by the opening of a switch or contact points, or the accidental breaking of a conductor.

Open Circuit Ignition.—That system of ignition in which the breaker contact points are normally open. The breaker contact points remain open until an instant before ignition is desired; the points are then closed and instantly open again to interrupt the primary circuit.

Opposed Cylinders.—An engine having cylinders set opposite, as a two-cylinder opposed engine having two horizontal cylinders in opposition.

Otto Cycle.—Same as *four-stroke cycle*. *See* Four-stroke Cycle.

Oval Pistons.—(1) Pistons originally round which are worn oval shape from friction against the cylinder wall, greater wear taking place on the sides because of thrust created by connecting rod angularity. (2) A piston purposely having less diameter across the piston pin opening to compensate for the greater expansion at this point due to the heat held by piston bosses.

Overhead Camshaft.—A camshaft mounted directly upon the cylinder head of an engine to operate valves in the head.

Overhead Valves.—*See* I Head.

Oversize Piston.—A piston larger in diameter than the original piston. Oversize pistons are fitted to cylinders when cylinders are enlarged by re-boring or grinding.

Parallel.—An arrangement of an electrical system in which all positive poles of units are joined to one conductor, and all negative poles to another conductor. Also known as *multiple*.

"Peening a Ring."—Refers to striking the inner side of a piston ring with a peening hammer to recover or set the ring's tension.

Permanent Magnet.—A magnet made of hardened steel which once magnetized retains its magnetism. To distinguish from an electromagnet having a soft iron core which is magnetic only during the time a current is passing through the coiled conductor around the core.

Piston Displacement.—The volume of gas displaced during one stroke of a piston. The volume of a cylinder in cubic inches with piston at lower center (bottom center). exclusive of the volume of the combustion chamber when piston is at top center. The area of the piston head multiplied by the stroke in inches equals the piston displacement in cubic inches.

Piston Head.—The top or closed end of a piston.

Piston Pin.—Also known as *wrist pin* or *gudgeon pin*. A pin supported in the piston bosses. Upon the piston pin the small end of the connecting rod oscillates.

Piston Ring.—*See* Compression Ring.

Piston Ring Groove.—The depression in a piston in which the piston ring fits.

Piston Skirt.—The lower part of the piston. The wall of the piston near the open end.

Piston Slap.—A light knock in an engine due to a loose piston striking or slapping against the cylinder walls.

Piston Travel.—The movement of the piston in the cylinder.

Piston Wall.—That part of the piston in contact with the cylinder wall.

Poppet Valves.—A name given to the orthodox mushroom valves in an internal-combustion engine due to popping open. To distinguish from slide valves or rotary valves.

"**Popping-back.**"—Term used in referring to explosions back through an inlet manifold and carburetor in a running engine.

Port.—The opening uncovered by a valve.

Positive.—That terminal of a generator of electrical pressure from which electricity is said to flow. Designated by a plus sign. The terminal of highest pressure or potential.

Power Plant.—The complete engine or means of obtaining power for an aircraft.

Power Stroke.—The third stroke of a four-stroke cycle engine. The working stroke, the firing stroke.

Preignition.—The ignition of the compressed gas in the combustion chamber before it is desired, due to either an early timed spark or from heated carbon deposit.

Pressure Fuel System.—That system in which air pressure forces the liquid fuel from the supply tank directly to the carburetor.

Primary Air.—Refers to the air opening in a carburetor below gasoline spray nozzle when an air valve is also employed above the nozzle, the latter being termed *secondary air*.

Primary Winding.—That winding of wire upon the core of an ignition transformer coil in series with the battery and breaker contact points. The short heavy winding upon the core of a magneto armature. The winding that creates the magnetic field in the ignition coil.

Primer.—Any device used to bring about a rich mixture for starting a cold internal-combustion engine.

Priming Carburetor.—Refers to flooding the carburetor by lowering the float in the float chamber thereby overflowing the spray nozzle, resulting in a rich mixture.

Priming the Engine.—Refers to putting raw gasoline directly into the combustion chamber of an engine to obtain a rich starting mixture.

Propeller End.—The end of an aircraft engine crankshaft to which the propeller is attached.

"**Pumping Oil.**"—Refers to the transferring of an excessive amount of oil from the engine crankcase up to the combustion chamber due to worn pistons or poorly fitted or broken piston rings.

Push Rod.—The rod used between the lifter and the rocker arm of an I-head engine when camshaft is in the crankcase.

Race.—(1) The hardened guide or track for balls in a ball bearing. (2) The running of an engine at a high rate of speed when under a light load or no load.

Radial Engine.—A type of aircraft engine having the cylinders arranged at equal intervals around the crankshaft. The term is commonly applied to the *fixed* or *static radial* construction having stationary cylinders arranged around the crankshaft.

Ratio of Compression.—As compression in pounds to the square inch depends upon the volume of a cylinder when piston is at top center in relation to the volume

of the cylinder when piston is at bottom center, the ratio is known as the *ratio of compression*, which is found by dividing the total volume by the clearance volume.

Reciprocating Engine.—Any engine in which the piston moves back and forth, to and fro.

Resistance Unit.—May refer to any resistance inserted in an electrical circuit. The ignition resistance unit is a coil of resistance wire in series with the primary winding of an ignition coil to control the flow of current by the varying temperature of the resistance wire. It also serves as a protection in event of ignition switch being left in the " on " position with breaker contact points closed.

Reversing Carburetor.—Refers to an installation of a carburetor so that the float chamber is on the opposite side from the original position.

Ribbon Ring.—A ring around a piston to retain a floating piston pin without any other locking means.

Rich Mixture.—That mixture in which gasoline is in excess of the desired amount or purposely near the limit.

Right Block.—The cylinder block of a V-type engine on the right when viewing the engine from the anti-propeller end.

Right-hand Engine.—That engine in which the propeller shaft turns clockwise when viewed from the anti-propeller end of the engine. A normal engine.

Right-hand Crankshaft.—A crankshaft having three pair of crank throws spaced 120 degrees apart in which the throws 3 and 4 are on the right when 1 and 6 are vertical and viewed from the forward end of the shaft. *See* description in text under Firing Orders.

Rocker Arm.—*See* Valve Rocker.

Rotary Engine.—A type of aircraft engine having radially arranged cylinders revolving around a stationary crankshaft.

Rotor.—The rotating member carrying a brush in an ignition distributor, or the rotating member without a brush which distributes the high-tension current in an ignition distributor.

"Running-in Engine."—The " working-in " or limbering up of a new or reconditioned engine. The operating of an engine under light loads at slow speed until the high spots on frictional surfaces have been polished off.

Safety Gap.—An air gap of from $\frac{5}{16}$ to $\frac{7}{16}$ in. shunted across the secondary winding of a high-tension magneto to allow current to find an easy return in event of a wire to any plug being removed. Without the safety gap the removing of a wire would result in injury to the secondary winding because of the high potential reached.

Scavenger Pump.—An oil suction pump used to maintain a dry upper crankcase in the *dry sump* oiling system.

Scavenging Stroke.—The fourth stroke of a four-stroke cycle engine. The exhaust stroke.

Scored Cylinders.—Deep cuts and scratches on the cylinder bore due to insufficient lubrication between piston and cylinder wall, a faulty piston ring, or a loose piston pin rubbing against the cylinder wall.

Secondary Air Valve.—A term employed for the auxiliary air opening in a carburetor when the air opening below jets is termed *primary air*.

Segment.—(1) A section of an ignition distributor which conducts electricity when rotor brush makes contact with segment. (2) A section or bar of a commutator on a motor or generator.

Self-starter.—Any mechanism which accomplishes the starting of an internal-combustion engine without cranking by hand.

Series Connection.—The connecting of electrical units or devices end to end in a circuit. Units of a circuit are in series when all the current flowing flows through each unit. The connecting of the positive terminal of a cell with the negative terminal of another cell to form a battery.

Set Spark.—*See* description in text under Ignition Timing.

Short Circuit.—An electrical circuit of low resistance, and particularly one which shunts another circuit of higher resistance intentionally or by accident.

Shorted Spark Plug.—A short circuit in the insulation of a spark plug either by carbon formation or a crack in the porcelain or other insulating material.

Shorting Spark Plug.—Refers to cutting the spark plug out of the circuit by grounding the terminal of the plug with a conductor.

Shuttle-type Armature.—Also known as H type. The conventional type armature having two poles. Used in magnetos.

Seized Pistons.—Refers to the seizing of the pistons by the cylinders of an engine when overheating expands the pistons, causing them to stick fast to the cylinder walls.

Side by Side Connecting Rods.—That method of arranging the connecting rods of opposite pistons in a V-type engine side by side on the crank pin. This arrangement is made possible by staggering the cylinders. To distinguish from *forked* connecting rods.

Single Wire System.—Refers to a starting and lighting system or an ignition system in which the metal work of an airplane or engine is used for the *return.*

"Skip."—An expression used in referring to a cylinder failing to fire now and then.

"Sneezing-back."—An expression sometimes used in referring to explosions back through the inlet manifold and the carburetor. Same as *popping-back.*

Solid Head.—Refers to the cylinder or cylinder block being cast in one piece. To distinguish from *detachable head.*

South Pole.—(1) The negative pole of a magnet. That pole of a magnet to which the lines of force are said to return. (2) That end of the compass needle pointing in approximately the direction of the south geographical pole. That pole which has an attraction for the north pole of a magnet. (3) The magnetic pole near the north geographical pole. *See* North Pole.

Spark Intensifier.—An air gap in series with the gap at the spark plug. An auxiliary gap which when placed external of the combustion chamber yet in series with the spark plug insures an open circuit in the secondary circuit of the transformer coil. The high insulation of the external gap prevents any leakage of current across the spark-plug gap when the breaker contact points close or open which may take place without an external gap when a fouled spark plug is being used in the combustion chamber.

Spent Gases.—Gases having no effective quality, as burnt gases expelled during the exhaust stroke of an internal-combustion engine.

Split-type Crankcase.—An engine crankcase that splits horizontally at about a center line with the crankshaft. To distinguish from the *barrel-type crankcase.*

Spray Nozzle.—A standpipe in the air passageway of a carburetor to spray the liquid fuel into the mixing chamber when a suction is exerted upon the nozzle.

Square Stroke.—Sometimes spoken of as a *square engine.* Refers to an engine in which the diameter of the cylinder measures the same as the stroke.

Staggered Cylinders.—A method of arranging the cylinder blocks on a V-type engine so that the connecting rods may be side by side on the crank pin for opposite cylinders. The center line of the cylinders of opposite sides are not in line. *See* Side by Side Connecting Rods.

Starving the Carburetor.—An expression used to describe a carburetor condition brought about by reducing the gasoline flow.

Step-up Coil.—*See* Induction Coil.

Straight Eight.—Refers to an eight-cylinder engine having all eight cylinders in a row. To distinguish from the eight-cylinder V-type engine.

Stroke.—The movement to and fro or in and out of a piston or any reciprocating member. The length of a piston's stroke is the distance the piston travels from top center to bottom center or vice versa.

Suction Stroke.—*See* Inlet Stroke.

Sump.—The oil reservoir at the lowest level of an engine lubricating system.

Supercharged Engine.—An engine equipped with a device for increasing the charge during the induction stroke above that supplied to the cylinders by atmospheric pressure.

Synchronize.—To cause to agree in time, as to time a magneto armature with the distributor so they agree in their timing. To cause an agreement in the timing of two separate ignition systems attached to one engine.

Taper of Piston.—Refers to the very slight taper of a piston, the greatest diameter being at the skirt, and a gradual decreasing of the diameter toward the head of the piston. The smaller diameter at the head of the piston is provided to allow for greater expansion due to higher temperatures at the piston head.

Tappet Gap.—Refers to gap or clearance between valve stem and the valve tappet.

Thermal Efficiency.—Refers to the heat efficiency of an internal-combustion engine.

Throttle.—A valve between the inlet valve and the carburetor of an internal-combustion engine to control the flow of gas by controlling suction.

Thrust Bearing.—A plain, ball, or roller bearing for taking pressure endwise, for instance, a bearing that takes end pressure in the direction of a shaft.

Timer Contact Points.—The ignition breaker contacts.

Timer-distributor.—The ignition unit consisting of breaker contacts and distributor.

Top Center.—The position of the piston when in its uppermost position.

Torque.—The turning effect.

Trammel.—An instrument for drawing ellipses. In reference to internal-combustion engines it refers to a stationary pointer or mark for measuring or checking marks upon a timing disc.

Tramming a Piston.—Refers to measuring the position of the piston in the cylinder for timing valves and ignition.

Transformer Coil.—An induction coil, also known as step-up coil or ignition coil. An electrical device for stepping up the low voltage obtained from the battery to a very high voltage capable of jumping the gap at the spark plug.

Two-stroke Cycle.—A series of events taking place in an internal combustion engine during two strokes of the piston.

Two Wire System.—That system of wiring in which a wire conductor is used for the return instead of the usual *ground return.*

U. D. C.—An abbreviation for *upper dead center.*

Upper Dead Center.—The same as *top center.*

Upper Crankcase.—Refers only to the upper half of an engine crankcase when the lower half contains bearings.

V-Type Engine.—A type of engine having two banks of cylinders forming the letter V when viewed from the end.

Vacuum.—A space entirely devoid of matter. A perfect vacuum is not obtainable, but a high degree of vacuum is obtained by an air pump or a piston in the cylinder of an internal-combustion engine during the suction stroke.

Valve Guide.—The bushing or boring in the cylinder casting through which the valve stem oscillates.

Valve Lag.—The late opening or closing of a valve.

Valve Lead.—An early opening or closing of a valve.

Valve Lifter.—The tappet or plunger between a cam and a valve.

Valve Overlap.—The condition of inlet valve opening before exhaust valve closes.

Valve Push Rod.—A rod between the lifter and the rocker arm of an I-head Engine.

Valve Rocker.—A rocker arm either at cam or located on cylinder head of an I-head engine.

Valve-in-Head.—Refers to that type of engine which has the exhaust and the inlet valve in the cylinder head. Also known as *I-head* or *overhead valves.*

Valves in Step.—Usually refers to the correct timing of the exhaust camshaft and the inlet camshaft in a T-head engine.

Valves Riding.—Refers to either valve or valves in contact with their tappets which prevents the proper closing of the valves.

Valve Tap.—A tapping sound from a defective valve tappet or cam, or from excessive clearance between the tappet and the valve stem.

Valve Tappet.—*See* Valve Lifter.

Vaporize.—To form a gas by the process of vaporization.

Vertical Engine.—A type of engine in which the cylinders are above the crankshaft.

Volt.—The unit of electromotive force (pressure).

Weak Compression.—Refers to compression which is lower than intended for an engine, due to leakage. Weak compression does not necessarily mean low compression, for 60 lb. compression would be weak compression in an engine originally having 80 lb.; yet 60 lb. would be good compression in a low-compression engine designed for a compression of 60 lb.

Wrist Pin.—*See* Piston Pin.

W-Type Engine.—A type of aircraft engine having three banks of cylinders and giving the appearance of the letter W when viewed from the end.

X-Type Engine.—A type of aircraft engine having four banks of cylinders, two banks forming an upright V, and two banks forming an inverted V, giving the appearance of the letter X when viewed from the end.

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